Iron production in low-shaft furnace plants with Indian raw materials

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SYNOPSIS

Compared with the rich deposits of high-grade iron ores spread in different parts of India, known reserves of Indian coking coal are not only limited but are also located in a particular geographical belt. Such an imbalance leads to the necessity of iron smelting with non-metallurgical coals particularly where the deposits of non-coking coal and lignite are also geographically disposed. The Low-Shaft Furnace Project was started at the National Metallurgical Laboratory, Jamshedpur, India, with the object of iron smelting with non-metallurgical coals and lignite coke; the former was employed also as low-temperature carbonized coke. These trials have covered three years now and have been based on smelting self-fluxing ore-coal briquettes also lumpy burden charges of raw materials from different parts of the country. A review is presented in this paper of typical operational results obtained including effects of dolomitic flux, particle size analyses of raw materials and slag basicity factors on the analyses of metal and slag vis-a-vis iron production, fuel rates and slag volumes. General economics of iron production in a low-shaft furnace have been explained particularly under Indian conditions of marketing foundry grades of pig iron, based on which recommendations have been made for the establishment of small iron production plants on a regional basis in India. SR78P

INTRODUCTION

CONVENTIONAL iron production in a blast-furnace is based on lumpy or agglomerated burden or their optimum combination employing strong and abrasion-resistant metallurgical coke. Smelting of iron in a low-shaft furnace can, however, be undertaken with non-metallurgical coke and lignite coke. The use of one component self-fluxing briquetted burden or lumpy charge of sized iron ore fines and fuel, has been investigated in the Low-Shaft Furnace Pilot Plant of the National Metallurgical Laboratory.

India has more or less uniformly dispersed deposits of good iron ore in the country. Coal reserves of India on a conservative estimate are figured at 20 000 million tonnes of which only 1 500 million tonnes are coking coal suitable for conversion into strong metallurgical coal. Deposits of metallurgical coal lie over a small geographical area on the Bengal-Bihar border in India. As such, iron smelting plants in different parts of India utilizing regional iron ores and non-metallurgical fuels present attractive possibilities thereby eliminating expensive and over-congested rail transport of foundry grades of pig iron which is subsidized by the State to maintain uniform selling prices thereof in all parts of the country.

LOW-SHAFT FURNACE PILOT PLANT OF THE NATIONAL METALLURGICAL LABORATORY

The Low-Shaft Furnace is of circular cross-section having a hearth diameter of 1 300 mm, a bosh diameter of 1 600 mm, and a diameter at the top of 1 300 mm. The heights of the hearth and bosh are 900 and 800 mm respectively, as shown in Fig. 1. The effective diameter at the tuyere level is 1 100 mm. The working height of the furnace from the tuyere level to the stock line is 2·6 m and the total volume of the furnace is 7·3 m^3. The top of the furnace is closed with a hopper and two revolving drums, each having a small segment open and a distributor. The furnace bottom, hearth, and bosh are lined with carbon blocks. It is lined with high alumina (40–42% Al_2O_3) around the tuyeres, and the shaft is lined with fireclay bricks (36–39% Al_2O_3). The blast is supplied by a single stage turboblower having an intake volume of 5 000 m^3/h with an outgoing blast pressure of 0·28–0·35 kg/cm^2 (4–5 lb/in^2). The blast is preheated to about 600°C by a heat-resisting recuperator heated by low-shaft furnace gas. The air passes through four water-cooled tuyeres each of 100 mm dia. into the furnace with a velocity of 95–100 m/s and at a pressure of 3 000 mm wg. The tuyere diameter can be changed to 40, 60, 70 and 85 mm by the insertion of reducers. The furnace shell is externally water-cooled. The tap hole and slag holes are at an angle of 180° and the height of the slag hole is 450 mm above the tap hole.

The furnace gas passes through two uptakes into an insulated dust-catcher. The temperature of the gas at the furnace top is maintained at 350°C by insulating the uptakes and the dustcatcher to prevent condensation of tar released in the stack from bituminous non-coking coal employed directly for iron smelting. From the dustcatcher the gas passes into a primary cooler where a spray of warm water collects the dust and tar at its bottom which are removed at intervals by a sloping worm. The temperature of the gas coming out of the primary cooler is at about 80°C and contains about 2 kg of dust per nm^3.

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TABLE I Composition of iron ores, %

No.	Location	Fe	SiO_2	Al_2O_3	S	P	Fusion point, °C	Apparent porosity, %
1.	Barajamda (Orissa)	59·92–64·50	3·20–6·34	4·10– 5·20	0·01–0·29	0·02	1 580	12·30
2.	Barbil (Orissa)	57·70–61·10	2·20–4·11	9·50–12·10	0·31	0·04	1 475	10·20
3.	Barbil (Orissa)	66·00	4·60	3·20	0·02	0·03	1 450	14·10
4.	Noamundi (Bihar)	63·00	3·50	6·00	0·04–0·30	0·13–0·22	1 450	27·70
5.	Andhra Pradesh	63·64	3·80–4·60	2·00– 5·90	0·03	0·06–0·12	1 424–1 500	13·16–17·31
6.	Chanda (Maharashtra)	64·30	3·10	2·50	Trace	0·03	1 530	25·00
7.	Mohindergarh (Punjab)	62·60	6·65	2·00	0·03	0·40–1·20	1 424	7·90
8.	Rajasthan	61·60	9·90	1·20	0·20	0·05	1 475	6·05

Before entry into the Thiessen disintegrator, light oils are separated from the cooling water by water syphon. The gas now at 25°C passes successively through the disintegrator, the drop catcher, and the final cooler where it is finally scrubbed with water. Water for gas cleaning is stored in a cooling basin and pumped into the gas system after prior cooling in a tube cooler. Basins have been provided for the collection of light oils and tar that are pumped out. The arrangements of the briquetting plant furnace and the gas cleaning plant are shown in Figs. 2, 3*a*, and 3*b*.

The quantity of water for furnace cooling is 140 m^3/h, and that for gas cleaning is 60 m^3/h ; the total requirement is over a million gallons a day, which is reduced to a total make-up water of 100 000 gallons per day by a water cooling and circulation system including that needed for slag granulation to the extent of 150 m^3/day. Chatterjea and Nijhawan[1] have discussed the possibilities of the low-shaft furnace process in India.

CHEMICAL ANALYSIS OF RAW MATERIALS

The chemical composition of various raw materials collected from the different states in India are given in Tables I to VI. The occurrence of essential raw materials and the potential sites for the installation of low-shaft furnaces are shown in a map of a part of India (Fig. 4).

Most ores used were characterized by high fusion points under oxidizing conditions; which may raise fuel consumption. Chemical analyses of fluxes are recorded in Table II.

Chemical analyses and caking indices of the coals and their ash are given in Tables III to VI. 'Kolsit' is made by low-temperature carbonization of non-coking coal from Singareni Colliery in internally heated ovens. L.T.C. is made from various non-coking coals in an externally heated oven.

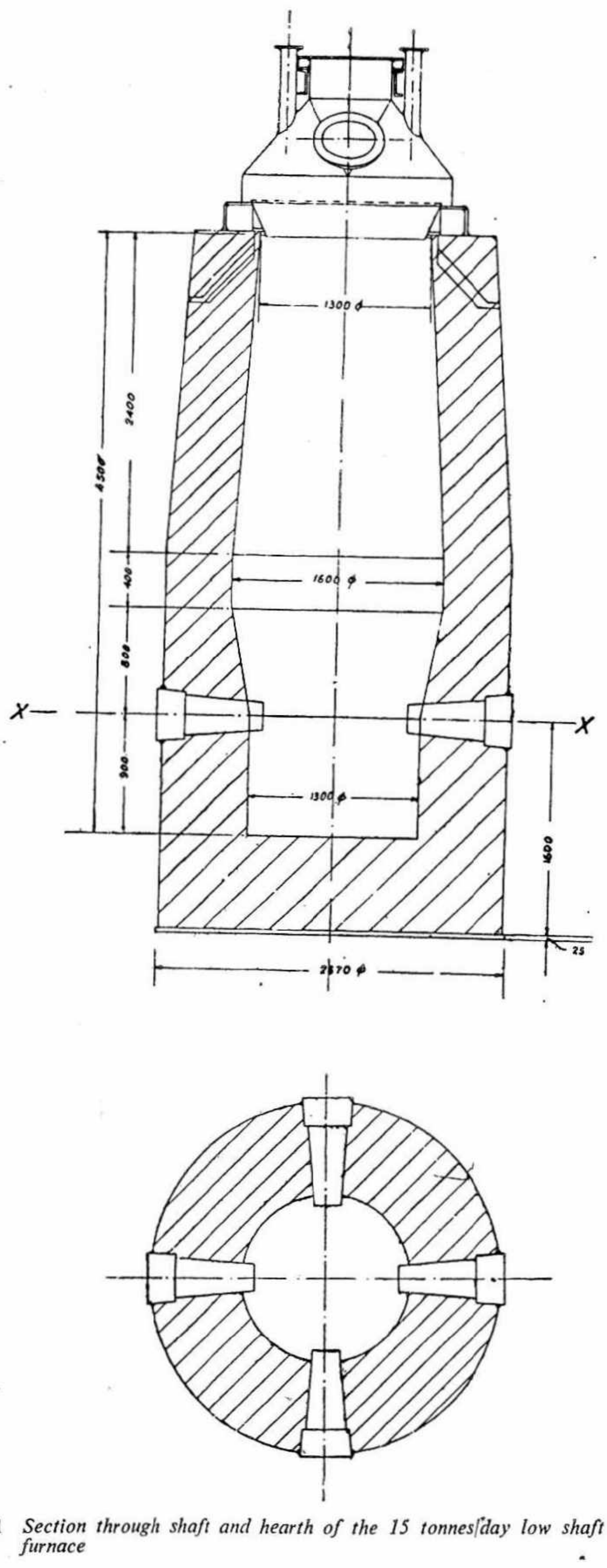
DETAILS OF SMELTING TRIALS

Smelting operation with a single-component burden

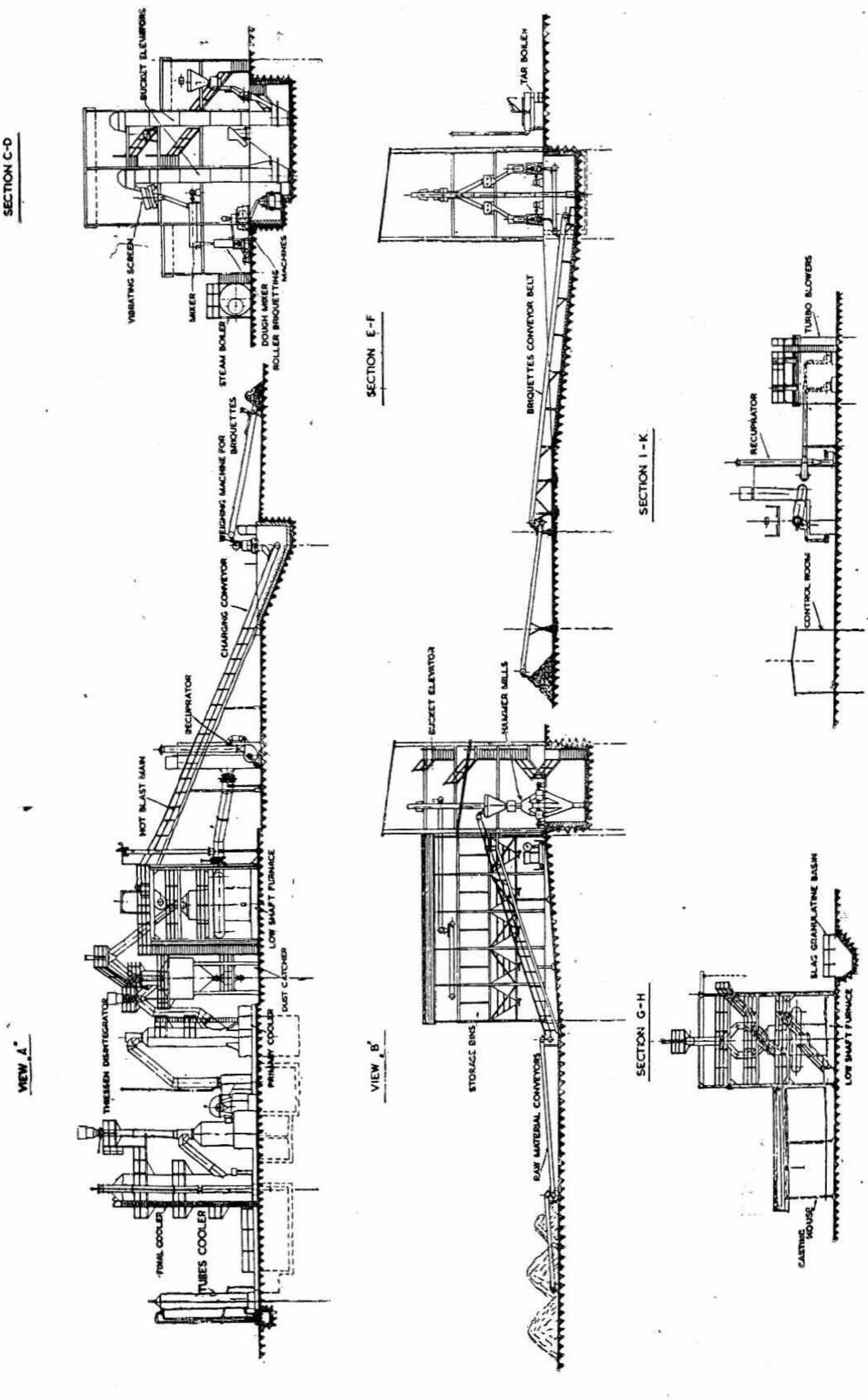
The single stage process developed by the Demag-Humboldt Niederschachtofen Gesellschaft, West Germany, depends on carbonization and smelting in a low-shaft furnace of self-fluxing briquettes containing iron ore, flux and non-coking coal in optimum proportions suitably bonded. The raw materials (0–5 mm) are briquetted with 4% coal-tar pitch and 4% sulphite lye as binders. The shape and size of a briquette is shown in Fig. 5. After ageing at room temperature for at least 24 h the briquettes should not burst on sudden heating from the atmospheric temperature to 350–400°C maintained at the top of the furnace and they should retain their shape until they reach the tuyere region to reduce unnecessary loss as dust. The caking index of coal and the reducibility of iron ore greatly influence the smelting process. Very little reduction of the iron oxide occurs in the upper part of the furnace, but rapid reduction begins at a height of about 1 m from the tuyere level, and 80% of reduction occurs during the passage of the briquette to the tuyere level.

At room temperatures, coal-tar pitch binder provided the strength to the briquettes whilst sulphite lye on decomposition at 160–180°C into intergranular envelopes strengthened the briquettes. At elevated temperatures the bonding strength due to binders disappeared and high-temperature strength of the briquettes was related to fusion of coal particles. Systematic investigations indicated that non-coking coals of extremely poor caking index did not provide such a fusion of coal particles or the strength to the briquettes for smelting. As the primary objective of smelting in a low-shaft furnace was to utilize non-coking coals, it became obvious that the briquetting process did not provide any space for their utilization.

Several compositions were tried for making self-fluxing briquettes in which the major variable was the use of



1 *Section through shaft and hearth of the 15 tonnes/day low shaft furnace*



2 *Side views and elevation of low-shaft furnace plant*

non-coking coals from different collieries. They are listed in Table III ; their compositions in Table VII. Noamundi iron ore fines (Table I, No. 4) and the limestone dust (Table II, No. 1) were employed in all compositions. In the absence of any coking properties, Wardha Valley and Kamptee non-coking coals (Nos. 15–17, Table III) could not be employed for briquetting at all unless the briquettes contained over 60% of good coking coal in the coal blend embodied in the briquettes.

The average screen analyses of raw materials for briquetting are recorded in Table VIII.

For smelting operations, the burden consisted of lump iron ore (5 to 15 mm), limestone (5 to 15 mm), and nut-coke (12 to 40 mm), in which the proportion of self-fluxing briquettes was progressively increased to 25, 50 and 75% until the burden consisted exclusively of self-fluxing briquettes. It was observed that with progressive increase of the briquette content, air blast developed high pressures following increased dust formation, which increased from 4% at 25% briquettes to 7%–10% of the weight of raw materials at 75% briquettes in the burden. Heavy dust formation following disintegration of the briquettes constituted the most difficult problem in their smelting.

The smelting of exclusively briquetted burden of necessity entailed faster blowing rates and in turn caused heavier dust losses and increased fuel rates. The pig iron analysis range was 2·8–3·75% C, 2·5–4% Si, 0·2–0·35% Mn, 0·01–0·1% S and 0·4–0·7% P whilst the slag analysis ranged from 34–41% CaO, 30–36% SiO_2, 0·5–0·9% Fe and 22–24% Al_2O_3. The top gas analysis was CO 24%, CO_2 4·5%, CH_4 5·5%, H_2 1·9%. The amount of CH_4 increased slightly with the progressive increase of briquettes in the burden. Dust generation on continuous smelting with briquetted burden steadily rose to 10% of the burden weight ; the size of dust particles also increased and the cycle caused a fluidized hanging mass of dust in the upper portion of the furnace, almost choking the air-blast passage and even rendering rates faster than the optimum blowing rates. The net result was serious bridge formation which on furnace manipulation designed to break the latter, caused initially a heavy void in the furnace shaft to be filled rapidly by uncarbonized briquettes reaching unprocessed to the tuyere zone apart from leading to a chilled hearth, the net results were serious and recurring blockage of furnace

TABLE II Analyses of limestone and dolomite %

Location	CaO	SiO_2	Al_2O_3	MgO
1. Birmitrapur (Orissa)	44·80	6·96	1·60	3·57
2. Andhra Pradesh	32·20	0·30	0·56	25·00
3. Salem (Madras)	54·31	0·88	1·23	1·01
4. Rajur (Maharashtra)	47·28	6·68	0·85	3·45
5. Birmitrapur (Orissa)	32·60	3·90	1·60	20·40
6. Assam/W. Bengal	31·30	0·63	0·40	20·70

TABLE III Proximate analyses, caking index of non-coking and coking coals.

Colliery	Moisture, %	V.M., %	F.C., %	Ash, %	Caking index B.S.S.
1. Jambad (Raniganj)	3·50	39·94	41·10	20·50	2
2. Samla (Raniganj)	4·50	34·00	47·50	14·00	2
3. Ghusick-Muslia (Raniganj)	4·50	31·10	38·80	25·60	6
4. Jaipuria (Raniganj)	3·20	35·00	41·00	20·50	2
5. Sirka (Bokaro) Raniganj-Karanpura)	3·50	30·80	49·52	19·70	2
6. Saunda (-do-)	3·70	31·00	51·50	9·80	2
7. Khaskenda (-do-)	6·60	35·90	45·20	12·30	2
8. Real Jambad (-do-)	4·70	33·60	43·90	17·80	2
9. Bankola (Raniganj)	4·00	32·00	44·56	19·40	2
10. Kargali (Bokaro) (Washed coking coal)	1·20	30·00	56·60	12·20	24
11. New Sitalpur (Disergarh coking coal)	1·50	36·30	49·30	12·90	20
12. Central Satgram (Raniganj)	3·40	36·00	43·00	17·60	7
13. Saltore (Raniganj)	2·50	36·40	48·80	12·30	9
14. Ghughus (Maharastra)	9·70	34·40	42·80	13·10	2
15. Kamptee Kanhan (Maharashtra)	5·00	34·00	37·80	23·40	2
16. Hindusthan Lalpeth (Maharashtra)	5·30	32·70	45·80	16·20	2
17. Singareni (Andhra)	7·10	26·10	49·50	17·50	2

TABLE IV Analyses of coal ash contents, %

No.	Origin	SiO_2	Al_2O_3	CaO	MgO	Fe	P	S
1.	Jambad	57·85	22·28	—	2·90	6·94	0·59	0·40
2.	Samla	62·96	22·82	4·56	1·63	5·09	0·60	1·01
3.	Ghusick-Muslia	63·73	21·93	1·09	2·40	5·43	0·15	—
4.	Jaipuria	53·28	23·00	5·43	1·63	9·18	0·51	0·39
5.	Sirka	54·26	27·26	2·74	1·05	6·57	0·50	0·63
6.	Saunda	61·20	31·90	2·70	3·10	2·70	0·46	0·54
7.	Khaskenda	49·04	24·93	2·44	1·33	4·37	0·59	0·48
8.	Real Jambad	61·50	27·80	2·10	2·20	4·40	0·33	0·31
9.	Bankola	56·30	24·46	10·42	0·39	4·59	0·37	—
10.	Kargali	46.30	29·70	3·92	3·35	5·88	0·33	—
11.	New Sitalpur	54·40	25·30	6·60	2·50	4·10	0·90	—
12.	Central Satgram	58.12	25·74	3·07	1·27	6·44	0·61	0·44
13.	Saltore	50·00	30·52	6·60	3·12	3·47	0·29	0·53
14.	Ghughus	57·80	35·00	3·70	2·80	0·59	—	—
15.	Kamptee Kanhan	55·00	34·90	2·90	3·20	2·90	0·11	1·30
16.	Hindusthan Lalpeth	42·80	47·00	4·80	2·30	1·80	—	—
17.	Singareni	65·60	22·80	1·30	1·40	6·30	0·058	0·21

TABLE V Proximate analyses of carbonized fuels, %

No.	Nature of fuel	Moisture	V.M.	F.C.	Ash
1.	Nut-coke	3·00	1·80	75·10	20·10
2.	Low-temperature carbonized coke (Kolsit-R.R.L.)	2·30	8·90	65·67	21·20
3.	,, (C.F.R.I.)	5·80	4·60	61·60	28·00

TABLE VI Ash analyses of carbonized fuels, %

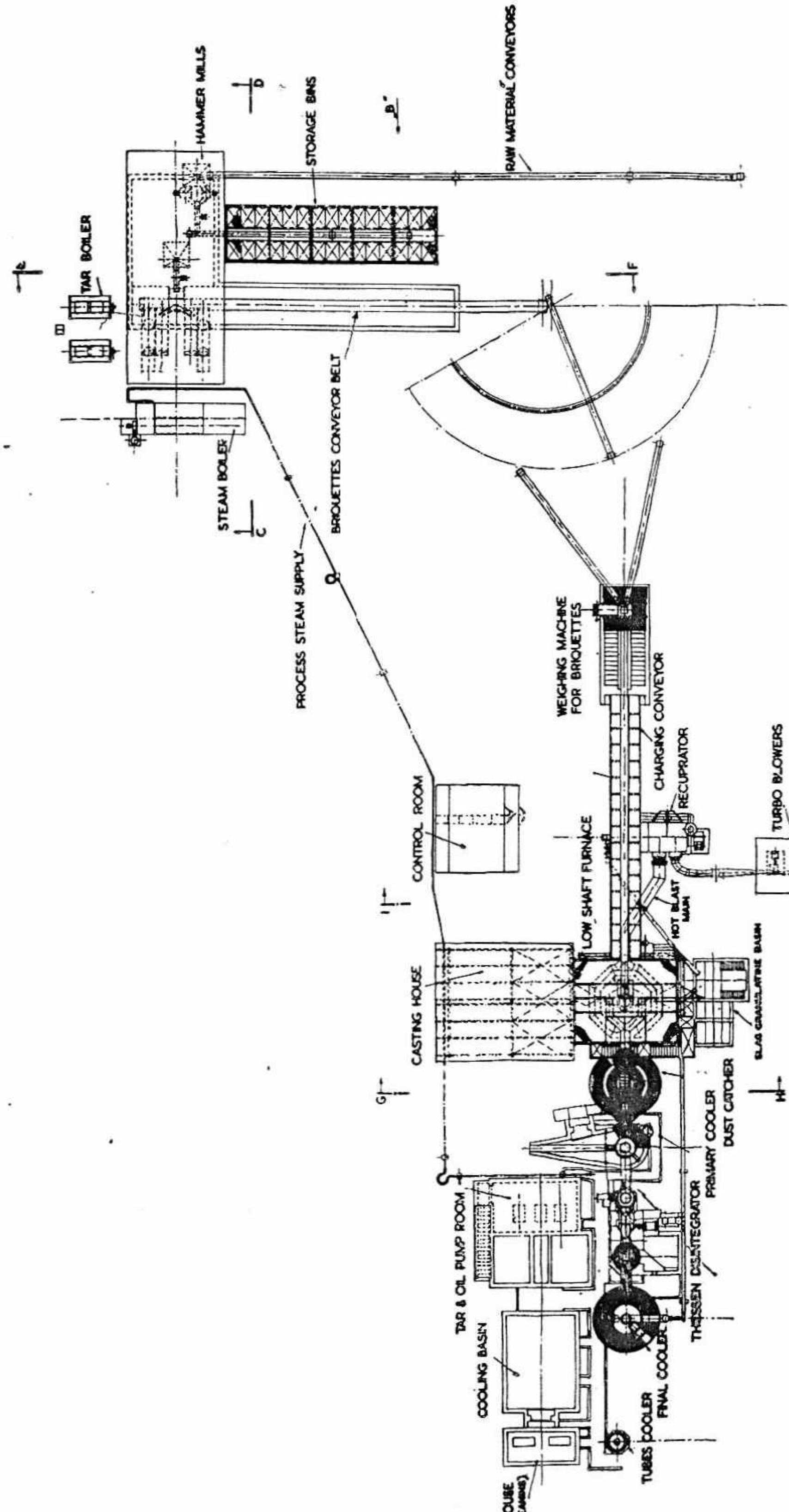
Origin	SiO_2	Al_2O_3	CaO	MgO	Fe	P_2O_5	S
1. Nut-coke	52·10	33·00	3·80	2·10	6·00	1·58	0·51
2. Kolsit (R.R.L.)	62·07	22·72	1·59	2·18	7·60	0·11	0·26
3. L.T.C. (C.F.R.I.)	56·31.	22·00	3·45	2·20	7·61	1·83	0·27

TABLE VII Compositions of briquettes

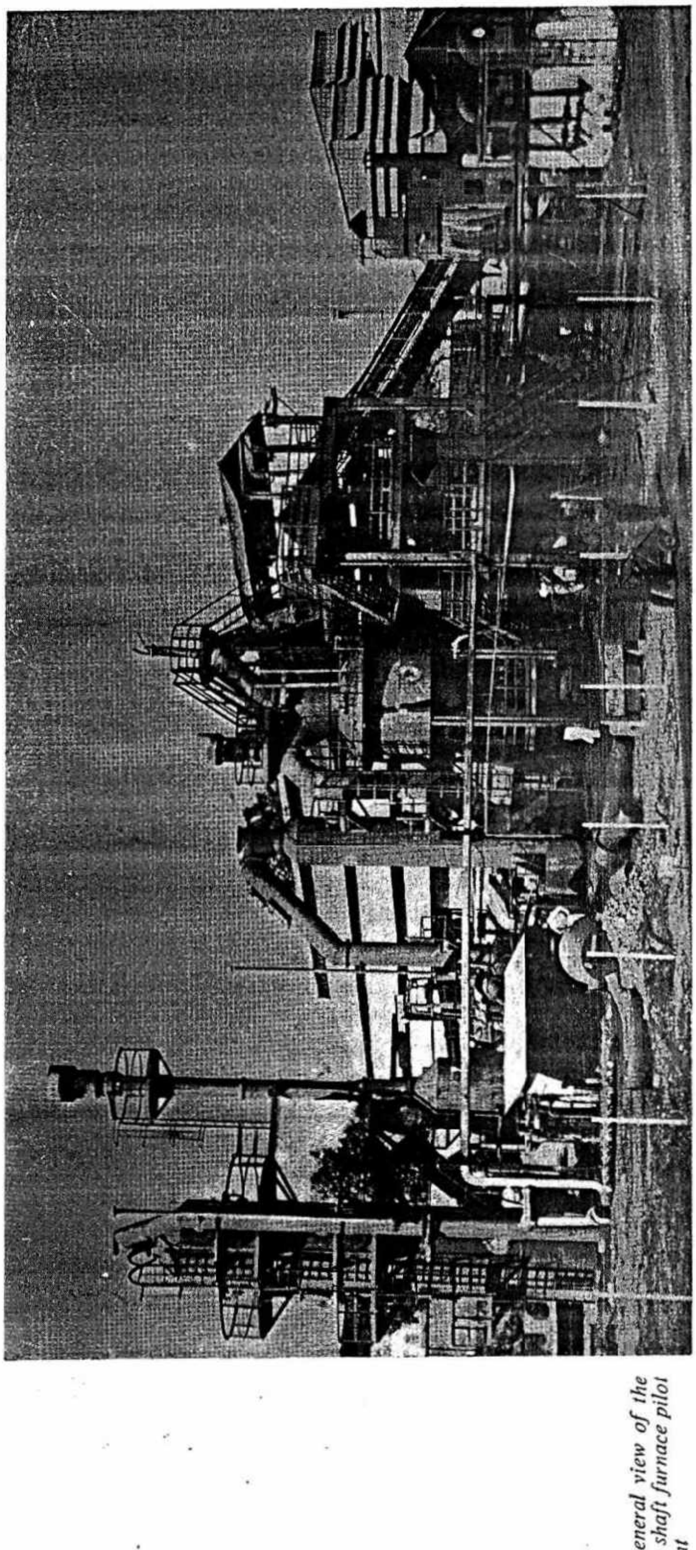
Type of briquette	Washed coking coal Origin	Percentage	Non-coking coal Origin	Percentage	Iron ore fines, %	Limestone fines, %
I	Bokaro, Kargali	27·7	Central Satgram	36·1	18·2	18·2
II	Bokaro, Kargali	30·0	Saltore	34·4	23·6	12·3
III	—	Nil	Saltore	64·5	23·2	12·3
IV	Bokaro, Kargali	41·5	Bankola	20·5	25·0	13·0
V	New Sitalpur, Disergarh	40·0	Sirka	19·0	25·0	19·0

TABLE VIII Screen analyses of raw materials for briquetting %.

Material	+2 mm	−2·4 to +1·0 mm	−1·0 to +0·5 mm	−0·5 to +0·25 mm	−0·25 to +0·15 mm	−0·15 mm
Iron ore	11·9	13·1	20·9	10·2	12·9	31·0
Limestone	25·0	28·1	17·5	1·5	11·1	16·8
Coal	12·9	21·9	27·7	9·6	14·6	13·3



3a General arrangement of low shaft furnace plant



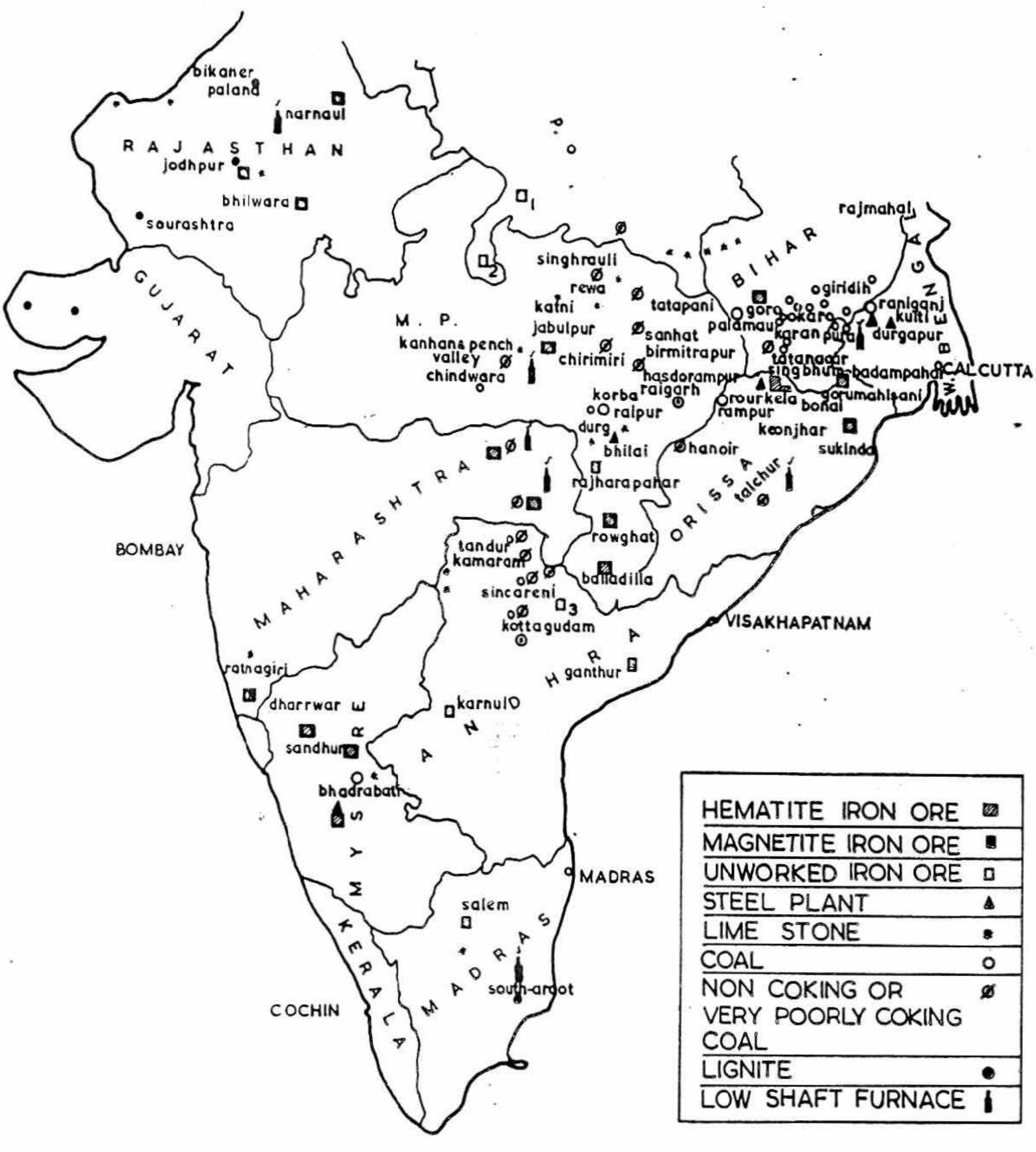
3b *A general view of the low shaft furnace pilot plant*

smelting which could not stand continuous operations. Although intimate contact of the briquetted ingredients was expected to promote reduction and lower fuel rate, the latter was higher compared to a burden consisting of nut coke and optimum sized iron ore, which was presumably due to heat requirements for carbonization of the coal present in the briquettes. For exclusive operations with briquettes made from Indian raw materials, about 100 tonnes of briquettes are necessary for the production of 15 tonnes of pig iron. To make 100 tonnes of briquettes requires 4 tonnes of sulphite lye and 4 tonnes of coal tar pitch as binders ; with the prevailing market price of the former at Rs 175/tonne and the latter at Rs 280/tonne, the cost of binders will be Rs 1 820 excluding the other raw materials, labour charges, depreciation, maintenance charges etc. In other words, the cost of binders alone per tonne of pig iron would amount to Rs 121 which precludes the commercial use of the briquetting process for iron production. The smelting of briquettes, therefore, did not show any attractive metallurgical or operational features. As such, the D.H.N. process of exclusive smelting of briquetted burden proved unpractical and uneconomical under India's conditions and had to be discarded.

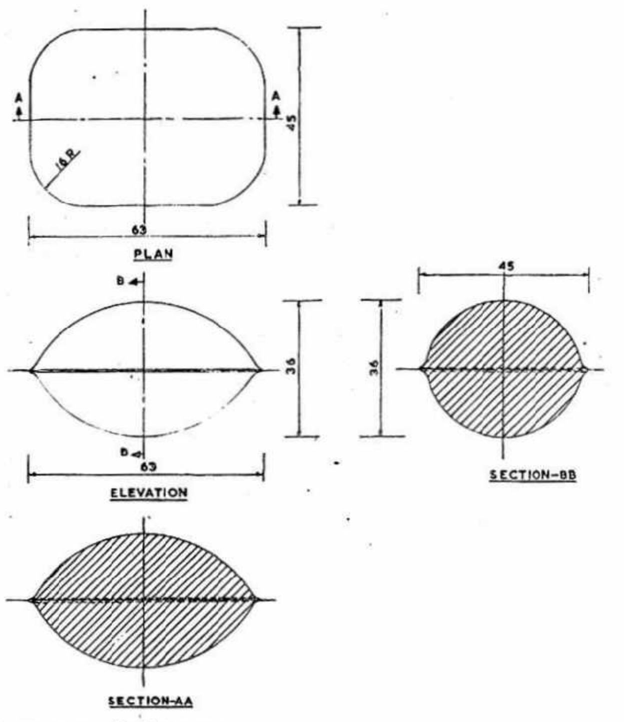
Investigations on smelting with non-coking coals—bedded form of burden

In view of serious disadvantages of smelting self-fluxing briquettes, it was decided to directly attempt the use of non-coking coals in a bedded form of burden. It was recognised that high coking properties of the coal directly charged will lead to sintering of the burden and affect its descent, and so coals of poor caking index were employed. It may be observed from Tables III and IV that these coals were characterized by high volatile matter and high ash contents, chiefly containing over 50% SiO_2 and 25% Al_2O_3. Low fixed contents and high ash in these coals contributed to high fuel input, and large flux additions were consequently necessary, resulting in excessively high slag volumes. It was, therefore, preferable to work with minimum slag basicity without sacrificing metal quality. Although the use of small particles of coke has been reported for iron smelting, continuous trials with non-coking coals have not been reported in technical literature.[2] During smelting at the National Metallurgical Laboratory, progressive replacement of nut-coke exclusively by non-coking coal was attendant with serious operational difficulties, although it was found that certain grades of wholly non-coking coals of very low caking index, non-friable in nature, which did not form a sintered mass on carbonization in the furnace stack could be directly employed for smelting pig iron in a low-shaft furnace. However, descent of the burden in irregular slips caused serious dislocations, disturbing the metal quality, increasing the fuel rate and causing heavy dust formation, when non-coking coal was directly employed for smelting. The burden also was not fully permeable for efficient gas flow and heat-exchange requirements. Apart from poor permeability, the presence of large quantities of fine grained material will also result in prohibitive dust losses. It was observed that a carbon rate of 2·3 tonnes/tonne of pig iron with lumpy iron ore of 10-30 mm size can be reduced to 1·85 tonnes/tonne with fine grained ore 5–10 mm size. However, the use of iron ore of small particle size (−5 m) exclusively led to operational difficulties. The lime basicity of the slag CaO/SiO_2 was maintained at 1·0 to 1·2. The average analysis of pig iron smelted was 2·6–3·8% C, 2·0–4·5% Si, 0·01–0·06% S and 0·5–0·7% P. The slag analysed CaO 30–40%, SiO_2 27–34%, FeO 0·9–1–2%, Al_2O_3 25–27%. The slag volume depended chiefly on the fuel rate, its basicity and varied from 1·2 to 1·6 tonnes/tonne of pig iron. The analysis of the top gas was CO 24 to 27%, H_2 1·7 to 2·5%, CO_2 3 to 6%, CH_4 3 to 5%. The CO/CO_2 ratio in the top gas varied from 5 to 8 instead of about 2 to 3 in conventional blast-furnace practice and depended on the particle size and reducibility of the iron ore and the rate of blowing which in turn affected the fuel rates. The most serious difficulty of smelting with high volatile bituminous non-coking coals is the formation of a sintered mass at higher level of the furnace stack, which affected the regular descent of the burden. Sudden breakage of a bridge or a scaffolding fed the inadequately prereduced and unprepared burden to the hearth zone causing cold hearth, high top gas temperature due to sudden release of gas, lower indirect reduction and higher fuel rate apart from excessive dust losses. As full utilization of the chemical and sensible heat of the gas is possible only when the burden descends regularly and optimum solid-gas contact and heat-exchange basis are established, the formation of bridges or occurrence of 'slips' seriously interferes with these requirements. The leading observation was that with non-coking coal employed directly for iron production, the smelting operations may be metallurgically feasible but were not practical on a sustained continuous basis. These views were further confirmed with smelting trials conducted with Saunda coal (Table III No. 6) and different iron ores (Table I No. 1, 2, 4). The particle sizes of raw materials are given in Table IX.

During the operation of the furnace with variations in the physical and chemical nature of the iron ore smelted, it was observed that the fuel consumption in terms of fixed carbon per tonne of pig iron varied from 1·7 to 2·0 tonnes depending on the particle size of the iron ore. The introduction of iron ore of progressively finer grain size caused increased dust formation up to 10% of the



4 *Map showing distribution of raw materials for iron and steel manufacture and probable sites for low-shaft furnace*



5 *Sections of a briquette*

burden charged. The presence of a small amount of nut-coke was found to be efficacious in assuring regular descent of the burden.

Smelting trials were also conducted with non-coking coal from Real Jambad Colliery [Table III (8)] with iron ore [Table I (2)]. The particle sizes of the ingredients are given in Table IX. The smelting was associated with high top temperature of 450–520°C which was attributed to large particle size of the fuel. Despite the large particle size of the fuel and other raw materials, dust production was high, amounting to 8–12% of the burden. The screen analyses of the flue dust are given in Table X.

Non-coking coal from Singareni Collieries (Andhra Pradesh)

Extensive investigations were conducted with non-coking coal from Singareni Collieries (Andhra Pradesh) [Table III (17)] with a variety of iron ores [Table I (2, 5)]. The particle sizes of the burden are given in Table XI.

Whilst the smelting with this coal was slightly better than with other non-coking coals, it was also characterised by irregularity of descent of burden which was attributed to the presence of increased −12 mm fraction in this coal.

In another smelting campaign, Singareni non-coking coal was smelted with iron ore [Table I (5)] and limestone [Table II (5)] from Andhra Pradesh. The dolomitic limestone contained 32% CaO and 25% MgO which made it exceedingly difficult to get a lime basicity ratio (P_1) of 1·2 without heavily increasing the slag volume. The burden was calculated with a nominal slag composition of 32% CaO, 30% SiO_2, 14% Al_2O_3 and 21% MgO. As expected, the smelting operations were irregular, leading to fluctuations in pressure and volume of air blast.

TABLE IX **Screen analyses of raw materials used with non-coking coals, %**

Material	mm −50+25	−25+12	−12+6	−6+3	−3	Remarks
Saunda non-coking coal	65·6	22·8	4·4	2·1	5·1	As received
Real Jambad non-coking coal	Big lumps broken to −100+25 mm					
Iron ore (lumps) (Orissa minerals)	Nil	51·9	28·0	9·2	10·9	
Noamundi iron ore lumps	Nil	64·3	23·9	11·8	Nil	
Iron ore chips (Orissa minerals)	Nil	4·5	26·8	50·1	19·6	
Iron ore (Barbil, Orissa)	Nil	12·7	63·7	15·6	8·0	
Limestone (Birmitrapur, Bisra, Orissa)	2·7	35·2	35·8	14·1	12·2	
Dolomite (do)	28·3	35·6	15·6	8·8	11·7	

TABLE X **Screen analyses of flue dust (Real Jambad coal), %**

Screen size B.S.S. −3+7	−7+16	−16+30	−30+60	−60+100	−100+200	−200
1·7	6·3	12·2	18·3	34·3	18·3	8·8

Smelting with Wardha Valley non-coking coals (Maharashtra)

The proximate analyses and ash analyses of these coals are given in Tables III (14–16) and IV (14–16) respectively. The coals were sub-bituminous and extremely poor in strength and highly friable. Smelting trials were conducted with iron ore and limestone from the Maharashtra State [Table I (6)] and [Table II (4)] respectively. With Kanhan-Kamptee coal, regularity of the smelting operations could be had with a maximum of only 32 per cent of the non-coking coal in the fuel burden balance being nut-coke. The exclusive use of Wardha Valley non-coking coals from Maharashtra was therefore completely ruled out. Even when used along with nut-coke in the proportion indicated above, the smelting will not stand continuous operation or give satisfactory results in terms of metal quality, optimum flux and fuel rates and slag analyses. Based on the characteristics of these non-coking coals, it was concluded that direct utilization of these non-coking coals was impracticable because of (i) heavy dust losses amounting to 10–12% of burden weight (ii) development of abnormally high pressure inside the furnace due to formation of a fluidized hanging bed of friable coal charged (iii) chilling of the hearth following bridging and their breaking up (iv) production of unacceptable grades of foundry iron and high fuel and flux rates and resulting abnormal slag volumes.

Smelting with low temperature carbonized coke made from non-coking coals (Kolsit)

Although a substantial quantity of pig iron was produced by the direct use of large varieties of non-coking coal (Table III), their industrial scale application in a low-shaft furnace was more or less completely ruled out. Besides, in the utilization of non-coking coals directly,

TABLE XI **Screen analyses of raw materials—(Singareni coal), %**

Material	−50+25	−25+12	−12+6	−6+3	−3
1. Singareni coal (As received)	19·80	28·90	24·80	18·80	7·70
2. Singareni coal (After screening)	23·40	57·50	15·90	2·30	0·90
3. Iron ore Table I (2)	—	3·90	60·40	15·00	20·70
4. Limestone Table II (2)	2·70	35·20	35·80	14·10	12·20
5. Limestone Table II (4)	—	13·40	32·50	19·10	35·00
6. Nut-coke Table V (1)	18·60	64·20	6·50	2·60	18·10
7. Iron ore	6·7	55·90	33·80	3·10	0·50
(Andhra)	24·80	55·30	18·20	1·20	0·50
Table I (5)	21·00	62·40	10·60	5·20	0·70

TABLE XII Screen analyses of raw materials used with 'Kolsit' %

Material	+25	−25+12	−12+6	−6+3	−3
1. Iron ore [Table I, (1)]	Nil	3·90	60·40	23·00	12·70
2. Birmitrapur limestone [Table II (1)]	Nil	2·70	31·80	36·30	29·20
3. Andhra limestone [Table II, (2)]	14·10	62·40	10·60	5·20	7·70
4· Kolsit (a) [Table V, (2)]	32·20	56·30	3·40	0·50	7·60
(b)	36·50	58·90	3·97	0·34	0·29
5. Andhra iron ore [Table I, (5)] (i)	6·70	55·90	33·80	3·10	0·50
(ii)	24·80	55·30	18·20	1·20	0·50
(iii)	21·00	62·40	10·60	5·20	0·70

(a) As received
(b) After screening through 12 mm screen

valuable by-products are lost, which can be recovered by carbonization of non-coking coals at suitable temperatures. It was, therefore, considered that utilization of low temperature carbonized coke with the elimination of moisture and recovery of volatile matter with consequent increase in its fixed carbon, better metallurgical reactivity and physical strength will not only improve the smelting characteristics but will also improve the overall economics of iron smelting. Extensive smelting campaigns were conducted with 'Kolsit', a low temperature carbonized coke made exclusively from non-coking coal (Singareni Collieries, Andhra Pradesh) in an internally heated Lurgi 'Spulgas' carbonization pilot plant operating at the Regional Research Laboratory of the C.S.I.R. at Hyderabad. The screen analyses of raw materials used are given in Table XII.

In smelting with 'Kolsit', generally two burden schedules were employed ; one consisting of iron ore [Table I, (1)], limestone [Table II, (1)], dolomite [Table II, (5)], having a particle size of −100+75 mm and the other of iron ore [Table I (5)], dolomitic limestone [Table II, (2)]. The smelting operation in either case was characterised by exceedingly regular burden descent with absence of bridging and hanging in the stack of the furnace. Likewise, high sulphur or silicon contents in the iron or high iron oxide in the slag or other irregularities such as chilling of the hearth were most conspicuously absent. The composition of slag evidently depended on the analyses of limestone employed. In the first case, the average analysis was 37% CaO, 30% SiO_2, 1·5% FeO, 23% Al_2O_3 and 8% MgO. The CO/CO_2 ratio in the top gas varied from 3·5 to 4·5 and a fuel rate of 1·28 tonnes of fixed carbon was achieved, whilst the slag volume amounted to 0·9 tonnes/tonne of pig iron. The exclusive employment of dolomitic limestone [Table II, (2)] yielded a slag containing 30% CaO, 35% SiO_2, 17% Al_2O_3, 0·8% FeO and 18% MgO resulted in a fuel rate of 1·95 tonnes associated with a slag volume of 1·4 tonnes/tonne of pig iron. The pig iron analysed 2·75−3·5% C, 2·5–4·0% Si, 0·01–0·09% S and 0·14–0·17% P. The furnace top gas analysed 23–25% CO, 4·5–5·0% CO_2, 6–7% CH_4 and 0·2–0·8% H_2.

TABLE XIV Operational data of the smelting processes under various slag basicities

Data on	Basicity degree $CaO/SiO_2=P_1$ 0·8	1·0	1·2	1·4
Calculated daily production tonnes	8·80	9·30	7·70	8·20
Fuel consumption F.C. tonnes/tonne of pig iron	1·48	1·50	1·51	1·54
Blast temperature (°C)	585	590	585	585
Flux rate tonnes/tonne of pig iron	0·88	1·01	1·20	1·35
Slag volume/tonne of pig iron	0.78	0·90	1·12	1·25
Composition of slag, %				
CaO	29·40	36·80	36·90	40·20
SiO_2	34·80	35·40	30·40	30·60
FeO	3·20	1·85	1·50	1·20
Al_2O_3	23·20	20·70	22·80	21·20
MgO	8·50	7·80	8·50	7·50
Pig iron composition, %				
C	2·80	3·10	3·20	3·80
Si	2·50	3·00	2·80	3·20
S	0·12	0·05	0·03	0·011
Mn	0·08	0·17	0·17	0·16
P	0·13	0·17	0·16	0·16
Gas analysis vol. %				
CO	25·30	25·50	25·60	24·50
CO_2	5·60	5·70	5·60	5·20
CH_4	5·50	5·70	5·10	6·20
CO/CO_2 ratio	4·50	4·50	4·60	4·70

Utilization of low temperature carbonized coke (C.F.R.I.)

Following the utilization of 'Kolsit', smelting trials were conducted with another variety of low temperature carbonized coke made exclusively from non-coking coals by carbonization in externally heated ovens in a pilot plant at the Central Fuel Research Institute of the C.S.I.R. The proximate and ash analyses of the L.T.C. are recorded in Tables V and VI (3). Iron ores of two different particle sizes and a blended flux were employed, screen analyses of which are given in Table XIII. The smelting operation was regular. The fuel rate of 2·03 tonnes/tonne of pig iron decreased to 1·81 tonnes/tonne of pig iron with the fineness of size of the iron ore yielding slag volumes of 1·65 and 1·52 tonnes/tonne of pig iron respectively. The high ash content of 28% in the L.T.C. led to high slag volumes whilst its large particle size contributed to higher top gas temperature and increased CO/CO_2 ratio in relation to corresponding operational results obtained with employing nut-coke or 'Kolsit'.

STUDY OF OPERATIONAL VARIABLES

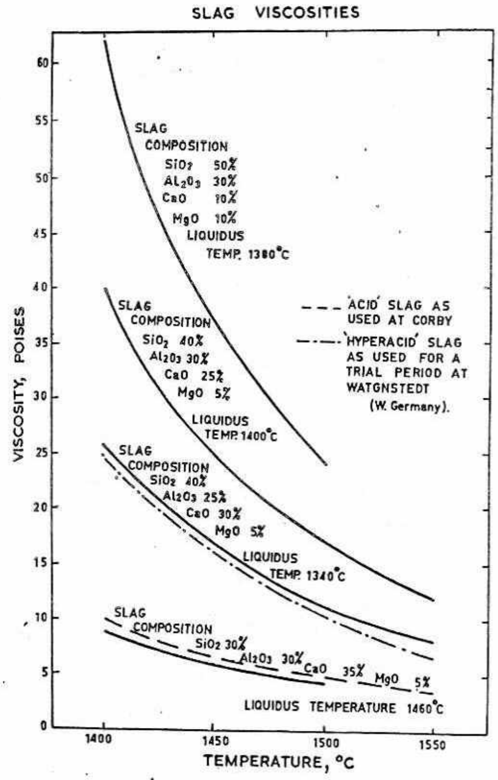
Smelting of foundry pig iron under different slag basicities

Acid smelting of iron has been tried for the utilization of

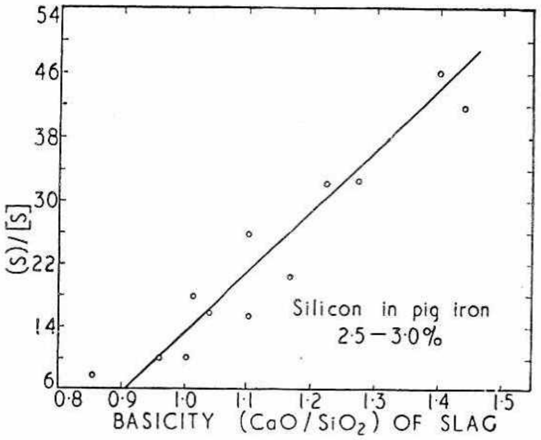
TABLE XIII Screen analysis of various raw materials

No.	Raw materials	% mm above 50	−50+25	−25+12	−12+6	−6+3	−3
1.	Punjab Ore (Lumpy)	—	24·9	48·8	16·2	2·6	7·4
2.	Punjab Ore (Medium size)	—	—	18·2	53·2	21·0	7·6
3.	Punjab Ore (Medium 50% Fine 50%)	—	—	16·3	20·1	25·0	28·0
4.	Punjab Ore (Fines)	—	—	—	8·2	37·0	54·8
5.	Low temperature carbonised coke* (Central Fuel Research Institute)	27·7	53·4	11·9	2·5	1·7	2·8
6.	Limestone (Madras)	—	30·9	27·3	17·2	7·9	16·7
7.	Limestone (Andhra)	—	16·7	45·9	16·1	61·1	15·2
8.	Nut-coke	—	18·6	64·2	6·5	2·6	8·1

* Made from non-coking coals, after initial screening through 12 mm screen to remove dust.



6 *Viscosity of several slags*



7 *Effect of basicity on the partition of sulphur*

poor grades of ores. Paschke and Hahnel[3] reported the results of operation with slag basicities of 1·59 to 0·22 in which the burden yield improved from 24·9% to 38·5%. Struve[4] conducted investigations on smelting in a low-shaft furnace with basicity ratios $\frac{CaO}{SiO_2} = P_1$ of 1·12 and 0·69. The requirements of limestone dropped from 916 to 870 kg and coke consumption from 1 890 to 1 627 kg/tonne of pig iron respectively whilst the burden yield and slag volume varied from 23·3 to 28·8% and 1 988 to 1 485 kg/tonne respectively. Despite the decrease in iron yield from 96·2% to 89·2%, the increase in metal productivity was about 4%. It was mentioned that a saving of 30 D.M./tonne resulted in acid smelting.

The fuel rate for iron smelting in a low-shaft furnace is higher than in a conventional blast-furnace primarily due to poorer indirect reduction. Increased fuel with its highly siliceous ash will need a large amount of flux addition for producing normal basic slag. The low-shaft furnace process is designed to exploit inferior grades of raw materials; lowering of the basicity may result in flux saving and improvement in fuel rates. The decrease in basicity below an optimum limit will, however, lower the sulphur capacity of the slag and external ladle desulphurization will become necessary.

With a view to examining the effects of changes in lime basicity ratio on the fuel rate, quality of pig iron, analyses of top gas, direct and indirect reductions, degree of desulphurization and particularly the technological aspects of operational performance, physical and chemical characteristics of the raw materials were kept identical with changes introduced in flux additions only to obtain CaO/SiO_2 ratios of 0·8, 1·0, 1·2 and 1·4 in successive stages. The operational data obtained under acid, neutral and basic slags are summarized in Table XIV.

A critical examination of the data revealed that the silicon in the metal did not appreciably increase with the lowering of the basicity through increase in the silica activity of the slag. The flux rate increased from 0·88 tonne to 1·35 tonnes with increase in slag volume from 0·78 to 1·25 tonnes per tonne of iron respectively. The slag, however, became exceedingly viscous on lowering CaO/SiO_2 ratio below 0·8 or raising it above 1·4 and consequently was not free flowing. The fuel rate increased with the basicity ratio of the slag. The carbon content was found to increase with increase in basicity of the slag. As was expected, the sulphur contents of the metal increased under acid slag smelting conditions and the slag exhibited a characteristic dark colour due to increased FeO contents therein. The recovery of iron and manganese in the metal decreased during acid smelting. Despite the lower additions of limestone and dolomite in acid slag smelting, the CO/CO_2 ratio of the top gas remained almost identical.

In this connection, reference is invited to work undertaken at the British Iron and Steel Research Association, on the subject of slag viscosities in the system CaO-SiO_2-Al_2O_3-MgO in the range of compositions of blast-furnace slag.[5,6] Some results of the British Iron and Steel Research Association work are shown in Fig. 6. Based on this work of BISRA it has been stated that 50 silica, 10 lime, 10 magnesia would be extremely viscous in spite of a low liquidus temperature. Some work has also been reported upon 40 silica, 30 lime at Watenstedt in Germany.[7] These trials may be worth trying out in India. Whilst the extremely acid slag looks too viscous, saving in limestone and expected increase in furnace productivity with 40 silica, 30 lime may be compensating factors but nothing definite can be stated unless full scale trials are made on Indian raw materials with the flux constituents indicated.

Chatterjea[8] has compared the chemical reactions in low-shaft furnaces with those in conventional blast-furnaces. The effect of the basicity of the slag on the partition of sulphur between the metal and slag is illustrated in Fig. 7. The ratio of sulphur in the slag to that in the metal rose from 7·5 with a slag basicity of 0·85 to 48 corresponding to a slag basicity of 1·4 when silicon in metal varied from 2·5 to 3·0%. The chemical reaction for desulphurization is

$$FeS + CaO + \tfrac{1}{2}Si = Fe + CaS + \tfrac{1}{2}SiO_2$$

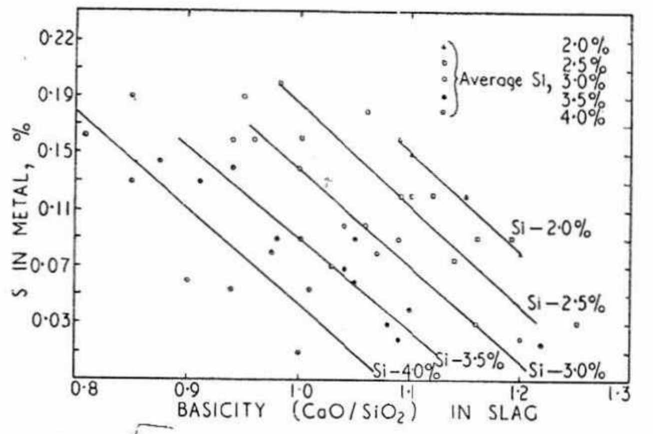
The equilibrium constant of the reaction is

$$K = \frac{\text{S in slag}}{\text{S in metal} \times \sqrt{\text{Si}} \text{ in metal}} \times \frac{\sqrt{SiO_2} \text{ in slag}}{\text{CaO in slag}}$$

The desulphurization index K_{si-s} is expressed by

$$\frac{\text{S in slag}}{\text{S in metal} \times \sqrt{\text{Si}} \text{ in metal}}$$

which indicates that high silicon in metal and high basicity promote desulphurization. Desulphurization indices



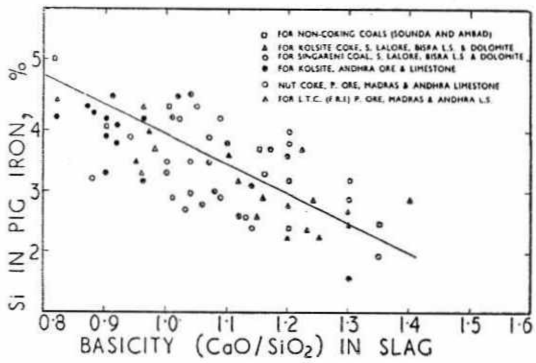
8 *Effects of silicon and basicity ratios on the partition of sulphur*

correlated with silicon and slag basicities are illustrated by a family of curves in Fig. 8. The basicity of slag greatly influences the partition of sulphur rather than silicon in pig iron. It is, therefore, preferable to adjust the basicity rather than increase the silicon contents of the metal to attain the desired sulphur contents therein.

Silicon and carbon contents in pig iron

In a low-shaft furnace, distance between the opposite tuyeres is very small in comparison with a normal iron blast-furnace. The high temperature smelting zone is concentrated over a small region and the so-called 'dead man's zone' is absent in low-shaft furnaces. These factors promote high silicon reduction. Metal collected from the tuyeres on taking off the blast analysed 24·6% Si. It showed that high silicon metal was produced just above the tuyere zone which reacted with FeO in the slag. Attempts to reduce the silicon below 2·0% by adjustments of either ore/fuel ratio or by increasing the slag basicity led to the chilling of the hearth and caused high FeO contents in the slag and high sulphur contents in the metal. The increase in basicity will lower the activity of silica in slag and is thereby expected to lower silicon content in metal. The effect of increase of basicity degree on silicon content of pig iron is shown in Fig. 9. The reduction of silicon in metal by one per cent from 4 to 3% will require increase in basicity from 1·0 to 1·2. The scatter of points with different raw materials clearly illustrates the difficulty of attaining less than 2·5% Si even at a basicity degree of 1·3.

Associated with high silicon in the metal, the carbon content of the iron was relatively low. Several measures were tried to carburize the metal. A piece of large size coke (about 10–15mm) was added per charge into the furnace for the purpose; although it helped slightly in raising the carbon, it was in general unsuccessful for raising the carbon appreciably as it possibly floated on slag. Following the partial success of the addition of large pieces of coke, it was considered that the small addition of coke breeze to the charge might be beneficial for the absorption of carbon by the metal on account of its fine particle size. The addition of a small amount of coke breeze in the charge, however, resulted in smelting difficulties referred to earlier, such as increased dust formation, hanging, scaffolding, whilst not raising the carbon content of the iron. Both these measures were, therefore, abandoned. It may not be out of place to mention here that the observation in this context was somewhat contrary to the observations made at the International Low Shaft Furnace where the carbon content of iron was found to increase with decrease in the coke



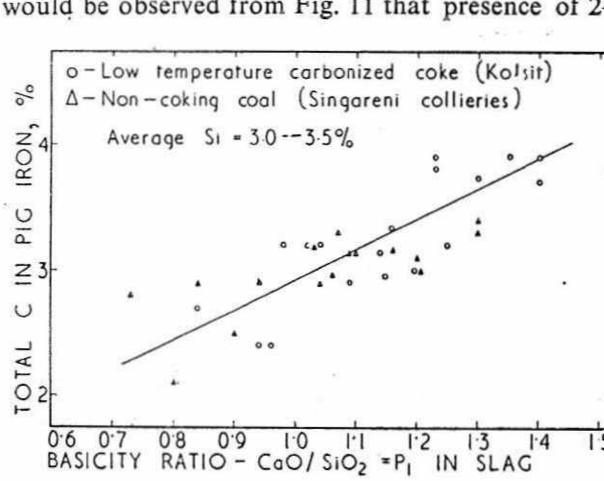
9 *The effect of basicity on silicon contents of pig iron*

size of the burden. The additon of dolomite to the burden helped in increasing carbon contents up to 4% which was attributed to the addition of optimum MgO in the furnace slag.

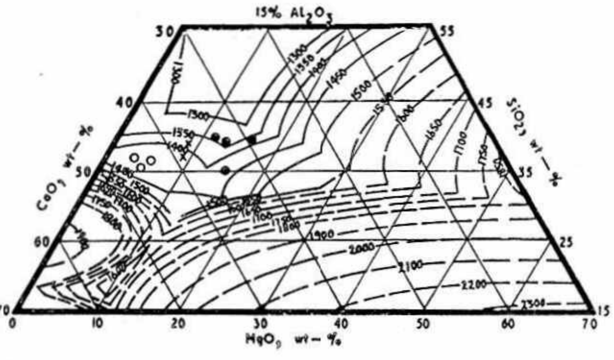
The effect of slag basicity on the carbon content of pig iron is shown in Fig. 10. The fuel burden consisted either of low temperature carbonized coke (Kolsit) or non-coking coal (Singareni Collieries). As high silicon content is associated with low carbon content, casts analysing 3·0–3·5% silicon and 0·02 to 0·06% sulphur have been plotted. It was shown that increase in basicity by 0·1 increased the carbon content by 0·25%. Struve[4] observed that change in slag basicity by 0·1 altered the carbon by 0·20%. Considered from this angle, acid smelting will produce pig iron of low carbon content unsuitable for foundry grades. The addition of dolomite resulting in 7–10% MgO in the slag was found to increase carbon content of the iron to 4%.

Addition of dolomite to the burden

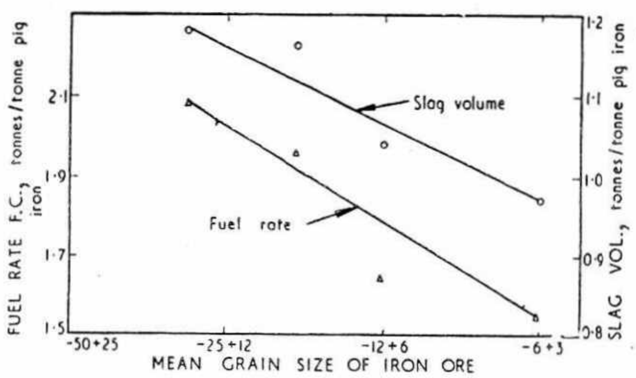
It was observed that in the absence of dolomite additions, the slags generally analysed 36–40% CaO, 32–34% SiO_2, 24–26% Al_2O_3, 2–3% MgO. The addition of dolomite resulting in 7–10% MgO in the slag in the basicity range $\frac{CaO}{SiO_2} = P_1$ of 1·0 to 1·4 was found considerably to improve the fluidity of the slag with considerable reduction of silicon and increase in carbon content of the metal. The composition of slags without dolomite addition, with dolomite addition resulting in 8–10% MgO in the slag and with dolomitic limestone addition resulting in 15–17% MgO in the slag at levels of 15 and 20% Al_2O_3 are indicated in Osborn diagrams in Figs. 11 and 12. It would be observed from Fig. 11 that presence of 2–10%



10 *Dependance of carbon contents of pig iron on basicity ratio*



11 *Liquidus temperature CaO-SiO₂-MgO slags at 15% Al₂O₃ level*



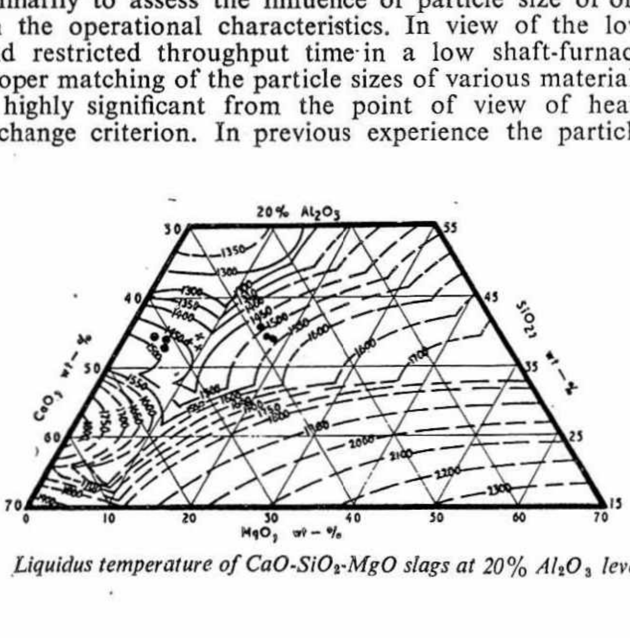
13 *Variation of fuel rate and slag volume with particle size of iron ore*

MgO in the slag containing 15% Al_2O_3 did not affect the liquidus temperature which was between 1 400–1 450°C. It may be observed from Fig. 12 that addition of MgO lowered the liquidus temperature of slags containing 20% Al_2O_3, when it was highly preferable to operate with a slag composition of 38% CaO, 32% SiO_2, 10% MgO and 20% Al_2O_3 possessing a liquidus temperature between 1 400–1 450°C.

In slags containing 15–17% MgO, the liquidus temperature was between 1 350–1 400°C. It was, however, noticed that despite the high $\frac{CaO+MgO}{SiO_2}=P_3$ value of such slags, with CaO 32%, 37% SiO_2, 16% MgO and 15% Al_2O_3 and its high volume, 1·4 tons per ton of iron, desulphurization of the metal was somewhat poor. It was considered that the replacement of certain amount of CaO by MgO beyond an optimum limit did not promote adequate desulphurization.

Influence of particle size of ore on smelting characteristics

Malcor[9] and Coheur[10] reported that despite the short height of the shaft, employment of fine grained raw materials lowered the top gas temperature within acceptable limits; it was concluded that the particle size of raw materials distinctly affected smelting operations. The replacement of lumpy limestone and/or ore by fine grained material appreciably lowered the top gas temperature. In view of the importance of utilization of fine grained materials, investigations were conducted with nut-coke with variation in particle size of iron ore primarily to assess the influence of particle size of ore on the operational characteristics. In view of the low and restricted throughput time in a low shaft-furnace proper matching of the particle sizes of various materials is highly significant from the point of view of heat-exchange criterion. In previous experience the particle sizes of the raw materials greatly influenced the temperature of the top gas, CO/CO_2 ratio of the top gas, fuel rate and the productivity of the furnace. It was considered that suitable adjustments of the particle size of the iron ore will not only promote indirect reduction leading to better CO/CO_2 ratio, but will also lower the top temperature of the gas, thereby reducing the loss of sensible heat. Both these factors will help in fuel economy. With these objects in view, the iron ore was screened into four dieffrent sizes as mentioned in Table XIII and investigations were conducted under indentical conditions with the only exception of the variations in particle sizes of the ore.



12 *Liquidus temperature of CaO-SiO₂-MgO slags at 20% Al₂O₃ level*

The operational data under the four different size classifications of the iron ore are summarized in Table XVII. An examination of the data revealed that the fuel rate decreased from 2·09 to 1·54 tonnes of fixed carbon per tonne of pig iron, with simultaneous decrease in the flux rate from 0·96 tonnes to 0·81 tonnes and decrease in the slag volume from 1·18 to 0·97 tonnes per tonne of pig iron respectively. The CO/CO_2 ratio in the top gas decreased from 6·4 to 5·4 which indicated improved indirect reduction. The average top gas temperature dropped from 410°C to 360°C. The use of fine grained materials obviously increased the dust production from 6% to about 10% of the burden weight charged. It was, therefore, concluded that there was a limit to the use of fine grained materials. Since excessively fine grained materials led to various operational complexities, such as irregular descent of the burden, difficulties in air blast penetration due to the reduced void space in the burden column, bridge formation in furnace stack in turn causing frequent opening of the safety explosion doors for the release of excess build up of pressure inside the furnace. The degree of fineness of the ore or limestone suitable for smelting also depended on the fuel employed. It was found that while ore fines containing 55% below −3mm [Table XIII (4)] would be compatible with nut-coke for attaining minimum fuel rate, a similar combination with non-coking coal would not be amenable to smelting due to various operational complexities indicated earlier. Heavy dust formation from the non-coking coal itself in the furnace will not permit the appreciable use of iron ore or flux fines.

This investigation was followed by a series of investigations in which two different sizes of iron ore (Punjab) were smelted with low temperature carbonized coke made from non-coking coals obtained from the Central Fuel Research Institute, Dhanbad. The smelting operation was quite smooth and regular without hanging or bridge formation. These investigations again confirmed that the fuel consumption considerably decreased with the fineness of the ore. The larger particle size of the

TABLE XV Operational data of smelting process under various sizes of iron ore

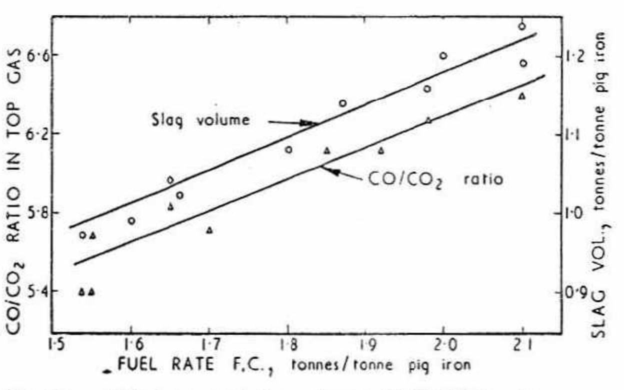
Particulars	Investigation–1	Investigation–2	Investigation–3	Investigation–4	Investigation–5	Investigation–6
Raw materials employed	Lumpy Punjab ore+nut coke	Medium size ore+nut coke	Medium 50% (size fine 50%) ore+nut coke	Fine size ore+ nut coke	L.T.C. (F.R.I.) +medium size ore	L.T.C. (F.R.I.) +ore fines
Fuel rate F.C./tonne of P.I.	2·09	1·98	1·65	1·54	2·03	1·81
Slag volume/tonne of P.I.	1·18	1·16	1·04	0·97	1·65	1·52
Iron ore/tonne of P.I.	1·47	1·47	1·47	1·47	1·47	1·47
Flux rate/tonne of P.I.	0·96	0·96	0·88	0·81	1·32	1·25
Average analysis of metal,%						
C	2·90	3·1	2·5	3·2	3·4	3·75
Si	2·60	2·9	3·0	3·7	2·6	3·27
S	0·07	0·11	0·06	0·06	0·1	0·11
P	0·66	0·58	0·63	0·68	0·87	0·64
Mn	0·25	0·32	0·26	0·38	0·53	0·80
Average analysis of slag, %						
CaO	39·84	38·1	41·2	37·90	40·4	35·3
SiO_2	33·40	38·48	33·6	34·20	37·64	42·4
FeO	0·88	1·0	0·77	0·67	1·1	0·55
Al_2O_3	17·00	18·0	19·78	20·30	15·9	18·05
MgO	8·30	5·3	5·6	6·40	4·8	5·0
S	1·07	0·84	0·95	1·2	0·71	0·62
P_1 (Calculated)	1·29	1·40	1·50	1·47	1·22	1·38
P_1 (Analytical)	1·19	0·9	1·22	1·10	1·07	0·8
Average gas analysis, %						
CO	25·00	24·0	24·0	26·8	23·0	24·0
CO_2	3·8	3·8	4·0	4·6	3·8	4·2
CH_4	3·6	3·4	3·50	3·0	4·2	4·5
CO/CO_2	6·4	6·3	6·00	5·4	6·0	5·7
Blast volume nm^3/h	2 700–3 000	2 500–2 800	2 200–2 500	2 200–2 600	1 900–2 300	1 900–2 100
Blast pressure mm wg	2 000–2 300	2 100–2 500	2 100–2 300	2 000–2 200	2 100–2 500	2 100–2 500
Hot blast temp. (°C)	580–600	575–590	560–580	580–590	580–600	580–590
Top gas temp. (°C)	380–440	350–420	350–400	320–380	350–420	340–400

fuel led to high top gas temperature and lower CO/CO_2 ratio compared to smelting with nut coke. The consumption of fuel in this case, was higher than that obtained with nut-coke which was presumably due to the above factors indicated. High ash content of the low temperature carbonized coke caused a high slag volume of 1·6 tonnes/tonne of pig iron. The operational data under these conditions have also been recorded in Table XV investigations 5 and 6 for comparison.

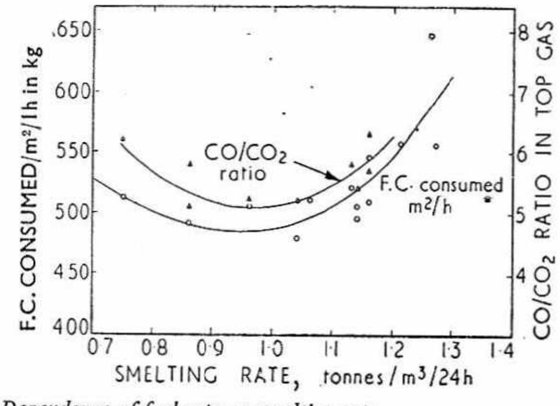
The influence of the mean size of the iron ore particles on the fuel rate and slag volume is illustrated in Fig. 13. The decrease in fixed carbon consumption from 2·08 to 1·55 tonnes associated with decrease in slag volume from 1·18 to 0·97 tonnes per tonne of iron respectively were obtained with decreasing size of the iron ore. A proper matching of the size of limestone may be expected further to improve the fuel rate. The fuel rate depends on the utilization of CO and high CO/CO_2 ratio indicates high fuel rates. A high slag volume also adversely affects the fuel rate. From a large number of observations, the dependance of fuel rate on slag volume and CO/CO_2 is illustrated in Fig. 14.

Smelting rate and fuel consumption

The height of the charge in a low-shaft furnace seldom exceeds 4·5 m. The reduction in height causes the burden to descend in 1½ to 2½ hours compared to 8 to 12 hours in a conventional blast-furnace. Since the time of passage of bosh gases through the stack is exceedingly small, a proper adjustment of the gas velocity and descent of the burden is necessary for optimum indirect reduction in furnace stack. It has been experienced in iron blast-furnace practice that there is a definite rate of smelting at which the coke rate is the minimum. The difference between high and low shaft heights contributes to different retention time index of gases. Bonnaure[11] mentioned that for a low shaft, it was 9 to 17 compared to 28 to 47 for blast-furnaces. At a very low rate of blowing, the upward thrust of the gases does not support the burden and therefore, incompletely reduced charge reaches the hearth. The rate of generation of heat is inadequate in relation to direct radiation losses. At the optimum rate of blowing, efficient exchange of chemical and sensible heat occurs. On further increasing the rate of blowing, the ascending gases pass away by 'channelling'. The in-



14 *Variation of fuel rate and slag volume with CO/CO_2 ratio*



15 *Dependance of fuel rate on smelting rate*

TABLE XVI Burden calculation for one tonne of pig iron

No.	Raw materials	kg	Fe kg	P kg	S kg	CaO kg	MgO kg	SiO_2 kg	Al_2O_3 kg
1.	Kolsit	1 764	33·18		0·91			242·72	81·54
2.	Andhra ore	1 484	920			9·48	7·58	62·33	59·36
3.	BISRA Limestone	580				259·84	19·14	28·86	9·28
4.	Andhra Limestone	170				54·74	42·50	0·51	0·95
	Total	3 998	953·18		0·91	324·06	69·22	344·42	151·13
	In the pig iron		932		0·4			75	
	In the slag		21·18		0·51	324·06	69·22	269·42	151·13

Elements in pig iron kg		%	*Constituents of slag* kg		Corrected, kg		% Corrected
932·0	Fe	93·2	27·18	FeO	27·18	FeO	3·23
—	Mn	—	—	MnO	—	MnO	—
35·0	Si	3·5	324·06	CaO	323·15	CaO	38·41
0·4	P	0·04	69·22	MgO	69·22	MgO	8·20
0·4	S	0·04	269·42	SiO_2	269·42	SiO_2	32·02
32·2	C	3·22	151·13	Al_2O_3	151·13	Al_2O_3	17·95
			0·51	S	1·14	CaS	0·13
1 000·00					841·24		99·94

Slag volume=0·84 tonne/tonne of pig iron. P_1 Corrected=1·19

Assumption ;

Fuel rate=1·2 tonne of F.C./tonne of Pig Iron.
Basicity (P_1) aimed=1·2
MgO% in slag=8·0%

fluence of smelting rate in tonnes/m^3/24 h on the coke rate and CO/CO_2 ratio is shown in Fig. 15 which depicts the three zones. The optimum rate of blowing with a particular set of raw materials consistent with minimum fuel rate will have to be determined.

CHARACTERISTICS OF SMELTING REGIONAL RAW MATERIALS AND THEIR ECONOMICS OF PRODUCTION

The annual demand of foundry grade pig iron in India is currently estimated at about 2 million tonnes, the present supply of about a million tonnes is chiefly met by blast-furnaces of integrated plants. The requirement of foundry pig iron will further increase in third and fourth Five Year Plans. In view of this, the Government of India has decided to license a million tonnes of pig iron production in regional small scale ironmaking plants. It has been rightly stated that to utilize a giant blast-furnace of hearth diameter of say 20 ft may not be advisable on economic grounds from considerations of productivity and capital investment returns. The capital investment per ton of pig iron in an integrated iron and steel plant is of a high order. As such, to utilise the giant blast-furnace of 22–23 ft and over hearth diameter for production of foundry grades of pig iron is tantamount in other words to producing a crude semi-finished product in a heavy integrated iron and steel complex instead of giving the same crude semi-finished product its logical steel end-product which will effectively ensure maximum returns on the heavy capital invested by the sale of fully finished products yielding thereby due profits and capital dividends. In many countries, foundry grades of pig iron are produced in blast-furnaces with say a hearth diameter of 14–15 ft. It would, therefore, be advisable to put in the smaller hearth diameter furnaces for the production of foundry grades of pig iron instead of utilising giant hearth diameter blast-furnaces for foundry iron output. As is well-known, cost of production of foundry grades of pig iron is higher than that of basic pig iron used for steel making; and any foundry iron made in a heavy integrated iron and steel complex is at the expense of corresponding, if not greater, output of steel and its finished products resulting in consequential unfavourable capital return values. This brings into prominence the question of production of foundry grades of pig iron in small iron making plants. In a few quarters, the economics of iron production in small scale plants has been questioned but it is considered necessary to

TABLE XVII Burden calculation for one tonne of pig iron

No.	Raw materials	kg	Fe kg	P kg	S kg	CaO kg	MgO kg	SiO_2 kg	Al_2O_3 kg
1.	Kolsit	2 059	38·73		1·06	13·28	8·85	283·32	95·18
2.	Andhra ore	1 484	920					62·33	59·36
3.	Bisra Limestone	675				302·4	22·25	45·25	10·80
4.	Andhra Limestone	200				64·4	50·00	·60	1·12
	Total	4 418	958·73		1·06	380·08	81·10	391·50	166·46
	In the Pig Iron		932·00		0·40			75·00	
	In the Slag		26·73		0·66	378·96	81·10	316·50	166·46

Elements in pig iron kg		%	*Constituents of slag* kg		Corrected, kg		% Corrected
932·0	Fe	93·20	33·38	FeO	34·38	FeO	3·50
35·0	Si	3·50	—	MnO	—	MnO	
—	Mn	—	380·08	CaO	378·96	CaO	38·71
0·4	P	0·04	81·10	MgO	81·10	MgO	8·20
0·4	S	0·04	316·50	SiO_2	316·50	SiO_2	32·33
32·2	C	3·22	166·46	Al_2O_3	166·46	Al_2O_3	17·00
			0·66	S	1·48	Cas	0·15
1 000·0		100·0			978·88		99·89

Slag volume/tonne of Pig Iron=0·98 tonnes. P_1 Corrected=1·19

Assumption :

Fuel Rate=1·4 tonnes of F.C./tonne of pig iron
Basicity (P_1) of slag (aimed)=1·2
MgO% in slag=8·0%

TABLE XVIII Burden calculation for one tonne of pig iron

No.	Raw materials	kg	Fe kg	P kg	S kg	CaO kg	MgO kg	SiO_2 kg	Al_2O_3 kg
1.	Kolsit	1 764	33·18		0·91			242·72	81·54
2.	Andhra ore	1 484	920			9·48	7·58	62·33	59·36
3.	Andhra limestone	830				267·26	207·50	2·49	4·65
	Total	4 078	953·18		0·91	276·74	215·08	307·54	145·55
	In the Pig Iron		932·00		0·4			75·00	
	In the Slag		21·18		0·51	276·74	215·08	232·54	145·55

Elements in pig iron kg		%	*Constituents of slag* kg		Corrected, kg		% Corrected
932·0	Fe	93·2	27·18	FeO	27·18	FeO	3·02
—	Mn	—	—	MnO	—	MnO	
35·0	Si	3·5	276·74	CaO	275·83	CaO	30·73
0·4	P	0·04	215·08	MgO	215·08	MgO	23·90
0·4	~~S~~	0·04	232·54	SiO_2	232·54	SiO_2	25·91
32·2	C	3·22	145·55	Al_2O_3	145·55	Al_2O_3	16·22
1 000·0		100·0			897·32		99·9

Assumption :

Fuel rate = 1·2 tonnes/tonne of pig iron.
Basicity (P_1) = 1·2

Slag volume = 0·89 tonne per tonne of pig iron. P_1 Corrected = 1·18

emphasize that each of the points raised can be most squarely dealt with. Apart from the position that there is no price control or retention price on foundry grades of pig iron made in small iron making plants which allows them thereby in effect greater profit per tonne of pig iron than is permitted in case of a heavy integrated iron and steel complex, the production of foundry grade pig iron in small blast-furnaces or low-shaft furnaces therefore assumes considerable significance and importance under Indian market conditions.

Several licences have been granted for small scale iron making plants in the country and it is high time that these plants were established through optimum use of either nut-coke or low temperature carbonized coke made out of non-coking coals or where electric power is readily available at optimum low rates, by electric smelting for iron production. There is also little doubt that the small scale plants have much less capital investment per annual tonne of pig iron output in relation to corresponding capital investment in an integrated iron and steel complex, yielding thereby specific economic advantages which cannot be lightly dismissed by any off-hand 'shrug of the shoulders' appraisals, apart from the fact that there is no levy of retention price and price control imposed on foundry grades of pig iron produced in small scale iron making plants. This naturally makes the operation of small scale foundry iron production plant significantly attractive than utilising the giant iron blast-furnace in an integrated iron and steel complex.

A. Andhra Pradesh

With a view to establish a small integrated iron production unit, the State Government of Andhra Pradesh sent iron ore, limestone, non-coking coal (Singareni Colleries) and low temperature carbonized coke made from the same non-coking coal for investigations. Successful smelting trials were conducted with low temperature carbonized coke made from Singareni non-coking coal.

Operations with low temperature carbonized coke made out of totally non-coking coals, containing 8–9% volatile matter and 65–67% fixed carbon were, however, characterized by exceedingly regular descent of the burden resulting in a suitable end-product i.e. foundry grade pig iron of desired analyses. The furnace top temperatures could also effectively be regulated between the desired level of 350–400°C. The CO/CO_2 ratio varied from 3·5 to 4·5 and a minimum fuel rate of 1·28 tonnes of fixed carbon/tonne of pig iron was also obtained, the low fuel rate can be attributed to much higher metallurgical reactivity of the low temperature carbonized coke (Kolsit). Dust formation was within tolerable limits and continuous furnace operation was fully feasible. By equating for lower temperature of the blast (585–595°C) compared to (800–850°C) in an industrial iron blast-furnace

TABLE XIX Burden calculation for one tonne of pig iron

No.	Raw materials	kg	Fe kg	P kg	S kg	CaO kg	MgO kg	SiO_2 kg	Al_2O_3 kg
1.	Kolsit	2 059	38·73		1·06	13·28	8·85	283·32	95·18
2.	Andhra ore	1 484	920					62·33	59·36
3.	Andhra limestone	968				311·69	242·00	2·90	5·42
	Total	4 511	958·73		1·06	324·97	250·85	348·55	159·96
	In the pig iron		932		0·40			75·00	
	In the slag		26·73		0·66	324·97	250·85	273·55	159·96

Elements in pig iron kg		%	*Constituents of slag* kg		Corrected, kg		% Corrected
932·00	Fe	93·2	34·38	FeO	34·38	FeO	3·32
—	Mn	—	—	MnO	—	MnO	—
35·00	Si	3·5	324·97	CaO	323·85	CaO	31·18
0·40	P	0·04	250·85	MgO	250·85	MgO	24·02
0·40	S	0·04	273·55	SiO_2	273·55	SiO_2	26·20
32·20	C	3·22	152·96	Al_2O_3	159·96	Al_2O_3	15·32
			0·66	S	1·48	CaS	0·13
1 000·00		100·00			1 044·07		100·17

Assumption ;

Fuel rate = 1·4 tonnes F.C. per tonne of pig iron.
Basicity (P_1) = 1·2

Slag volume per tonne of pig iron = 1·04 tonnes. P_1 Corrected = 1·18 practice, uninterrupted operations over long periods and adjustment of particle size of other raw materials, considerable reduction in fuel consumption can be most successfully effected with consequent significant improvements in overall economics of production. It is, therefore, reasonable to assume that continuous operations on an industrial scale in a furnace of 100–150 tons/daily output of iron with adequate facilities for crushing and screening of the raw materials and a hot blast temperature of 800°C will effectively bring down the fuel rate to 1·1 to 1·2 tonnes of fixed carbon per tonne of pig iron.

Calculations of burden based on the use of Kolsit with Andhra iron ore, and a mixture of limestone of usual grade with dolomitic limestone of Andhra Pradesh based on fuel rate of 1·2 tonnes of fixed carbon per ton of pig iron, or 1·4 tonnes of fixed carbon per tonne of pig iron are tabulated in Tables XVI and XVII.

Similarly, exclusive use of Andhra raw materials consisting of Kolsit, Andhra ore, and Andhra limestone based on a fuel rate of 1·2 or 1·4 tonnes of fixed carbon per tonne of pig iron are recorded in Tables XVIII and XIX.

From a comparison of these two tables, it is apparent that partial replacement of Andhra dolomite limestone by a suitable limestone containing lesser amounts of MgO would reduce the slag volume and would enable the furnace to be operated with a fuel rate of 1·2 tonnes of fixed carbon per tonne of pig iron under industrial plant conditions.

Economics of iron production in the industrial low-shaft furnace

It will be only fair to state that the economics of production of foundry grades of pig iron based on detailed investigations undertaken at the Low-Shaft Furnace Pilot Plant of the National Metallurgical Laboratory could not at this stage of its operation be altogether conclusive and may tend to be somewhat premature, whilst at the same time the investigation results provide pointed and clear indications of what would be expected on an industrial plant of the size and daily production capacity that could significantly interpolate the pilot plant scale results and yield desired economics of production. It is also to be emphasized that the pilot plant trials of the great magnitude as the Low-Shaft Furnace Pilot Plant of the National Metallurgical Laboratory clearly highlight the importance of full utilization of all the by-product values, if the economics of integrated plant operations have to be improved to bring them into expected industrial levels. In this particular case, the by-products should be fully made use of, which, of course, cannot be attempted in the Low-Shaft Furnace Pilot Plant of the National Metallurgical Laboratory itself in view of the restricted scope of the Pilot Plant Project. However, in an industrial plant, the following by-product recoveries will have to be effected on full industrial scale and due credits thereof would have to be included while assessing the economics of production.

(*a*) Full utilization of the low-shaft furnace gas with its high calorific value of 1 300–1 400 kcal/nm^3 : it is stated here that in the Pilot Plant trials undertaken at the National Metallurgical Laboratory only 1/3rd of the clean furnace gas was utilized for pre-heating the air blast. In an industrial plant, the remaining 2/3rd of the gas must be effectively utilized, thus improving the overall economics most favourably. In all iron and steel plants, the entire gas is cleaned, recovered and fully utilized in diverse ways.

(*b*) The low-shaft furnace slag can be used in several ways to improve the overall economics, such as for the production of slag cement, cement aggregate, hollow building blocks, slag wool and so on. The necessity for utilization of low-shaft furnace slag and other by-products in case of an industrial unit is far more imperative than in an integrated million tonnes/year steel plant hitherto operating in this country. Why the subject mentioned is being highlighted is because no heavy integrated iron and steel million tonnes a year unit has so far utilized blast-furnace slag on an industrial level for the production of slag cement etc.—lately the Tata Iron and Steel Company have put up a unit in collaboration with Associated Cement Company. Therefore, while an integrated million tons a year steel plant may afford not to utilize the slag value, in a much smaller low-shaft furnace industrial plant this non-utilization of the slag can hardly be permitted.

(*c*) In the case of totally non-coking bituminous coals whose direct charging leads to evolution of considerable bituminous volatile matter which can clog the upper regions of the furnace and the uptakes etc. and whose incorporation in the form of briquettes has already been dealt with in the preceding pages, this can also be responsible for unfavourable cost factors.

Another point which adversely affects the cost of production in the low-shaft furnace is that in India the cost of coal is based on its ash content and not on its coking properties with the results that a non-coking coal with somewhat lower ash could be more expensive than a coking coal with relatively somewhat higher ash content. Since the low-shaft furnace is not based on the use of hard metallurgical coke of necessity it will have to utilize greater tonnages of non-coking coals—the volatile matter of these coals will naturally be included in the furnace gas liberated and to some extent it will be cracked in the upper regions of the furnace rather fruitlessly. If the bituminous non-coking coals contain, say, 20 per cent ash and about 30–40 per cent volatile matter, the fixed carbon available for metallurgical load purposes will merely be of the order of less than 45 per cent. It will thus be appreciated that fuel consumption of the non-coking coal used as such will naturally be much higher than that encountered in integrated steel plants. It is, therefore, suggested that the low temperature carbonization plant should be incorporated as mentioned earlier and this will be useful from more than one point of view. The capital cost of building the low temperature carbonization plant will also be of about the same order as the corresponding briquetting plant unit. However, in the case of a low temperature carbonization unit, the by-product recovery from the coke oven gas can be a source of potential market value—this would naturally improve the overall economics of iron production.

Even if a low temperature carbonization unit is not put up and a favourable non-coking coal low in volatile matter is used directly, credit will have to be given for the recovery of by-products such as tar and light oils from the clean furnace gas.

Considered on the basis of the above by-product recovery prospects and the incorporation of preheated air blast temperatures of the order of 800–850°C which are fully practicable in industrial low-shaft units, the fuel consumption can be favourably and appreciably reduced. In this connection, it is stated that the air blast temperature at the Bhilai Steel Plant is higher than those prevailing in other steel plants in India which is understood to be of the order of 850–900°C and is likely to be raised still higher. In an industrial plant based on the low-shaft furnace pilot plant process, it would be fully practicable to obtain high blast temperature by the use of suitable recuperators and regenerator units and this would naturally lower the overall cost of production.

For an industrial unit, it is therefore recommended to include (*a*) all by-product recovery units, (*b*) low temperature carbonization unit for carbonizing non-coking coals of different types and (*c*) incorporation of high blast temperature apart from ensuring integrated operations of the entire plant through the use of sized burden calculated to yield maximum iron productivity consistent with optimum fuel rates.

Based on these considerations, it is reasonably expected that the cost of production in an industrial low-shaft-furnace unit of the size of 100 000 tonnes of pig iron per year will be of the same order, if not less, as that of electric iron smelting plant operating elsewhere. The low temperature carbonized coke is far more reactive than the hard metallurgical nut-coke which is an alternative fuel for iron smelting in low-shaft furnaces, but in the latter case, the shaft height of the furnace will have to be proportionally raised to keep the furnace top temperature within controllable limits. It is expected that in an industrial plant of the capacity of 100 000 tonnes of pig iron a year or more, incorporating all the items stated above, the fuel consumption could be of the order of 1·3 to 1·6 tonnes of low temperature carbonized coke per tonne of pig iron ; if the low temperature carbonization plant is part and parcel of the low-shaft integrated plant, the cost of low temperature carbonized coke will have to be assessed on the basis of by-product recoveries and could be lower than the hard metallurgical nut-coke.

The flux consumption correspondingly will depend on regional availability of fluxes. The composition of the

TABLE XX Norms for the operation with Kolsit and Singareni coal

Operation with Kolsit				*Operation with Singareni coal*	
Actual 'A'		Estimated 'B' for a 100 000 tonnes a year production plant		Actual 'A' Pilot Plant	Probable 'B' (100 000 tonnes production plant
Per tonne of pig iron produced (in tonnes)				Per tonne of pig iron produced (in tonnes)	
	(1)			(2)	
Iron ore	1·50	Iron ore	1·50	Iron ore	1·50
Limestone	1·10	Limestone	0·75	Limestone	1·81
Kolsit	2·85	Kolsit	1·80	Non-coking coal	4·50
(1·9 F.C.)		(1·2 F.C.)		(2·25 F.C.)	

The fuel consumption per tonne of pig iron is an important factor in the production costs, has been adequately extrapolated from the Pilot Plant trial results to those expected in an integrated industrial plant of the annual output under reference. The increase in the furnace size and output coupled with consequent decrease in the flue dust generated, constancy of smelting operations under uniform raw-material's supply over long periods of operations, higher hot-blast temperature, regular descent of the burden and resulting operational metallurgical improvements will all contribute to effective lowering of the fuel rate. Considering all these factors, it would be reasonable to assume that a fixed carbon rate of 1·2 tonnes per tonne of pig iron can effectively be achieved under industrial conditions with even further possibilities of economy in fuel rates.

As a fixed carbon rate of 1·28 tonnes/tonne of pig iron smelted at times achieved under Pilot Plant trials, fuel consumption of 1·2 tonnes of fixed carbon or 1·8 tonnes of Kolsit per ton of pig iron can easily be achieved under industrial plant control and operational conditions. Further, allowing for the recovery in full of potential by-products and credits thereof resulting in a price of Rs. 40 per tonne of Kolsit has been assumed. In an industrial plant, the price of Kolsit will need to be assessed in relation to its rational requirements for iron smelting in Andhra Pradesh and not on its 'industrial' producing and sale factors—the sale price of low temperature carbonized coke produced in Jharia is Rs. 29 per tonne only.

Partial replacement of dolomitic limestone by high CaO bearing limestone, prior crushing and screening of raw materials, increase in hot blast temperature, continuity of smelting and plant operations under uniform conditions of raw materials will reduce the fixed carbon rate to 1·2 tonnes or 1·8 tonnes of Kolsit/tonne of pig iron.

With direct use of the coal, even though metallurgically, the smelting is feasible and has been successfully accomplished in the Pilot Plant trials of the National Metallurgical Laboratory, potential by-products of coal are lost. Excessively high fuel rate and prementioned furnace operation difficulties do not favour direct utilization of coal for iron production in Andhra Pradesh. In view of this commercial adaptation, cost calculations thereof are not considered.

TABLE XXI Initial production cost estimates per tonne of pig iron based on an annual output of 100 000 tonnes of pig iron

Description	Required per tonne of pig iron	Cost per tonne of pig iron inclusive of freight etc.	Total cost/ tonne of pig iron
1. *Materials* (Suitably screened and sized)			
(i) Iron ore*	1·50	Rs 18·00	Rs 27·00
(ii) Limestone	0·75	Rs 16·00	Rs 12·00
(iii) Low temperature carbonized coke (1·2 F.C.)	1·8	Rs 40·00	Rs 72·00
(*For comparison, the cost of iron ore is Rs 16 per tonne in Bhilai Steel Plant, whilst, in an earlier Report of consultants to Hyderbad Government, a price of Rs 40 per tonne of iron ore stipulated.)			
Total Material Cost			Rs 111·00
2. *Power requirement*			
(i) Power expenses including the chief power consuming factor i.e. air blast blowers and other auxiliaries.†			Rs 10·50
(†In a million tonnes a year steel plant corresponding figure is Rs 8·60/tonne of pig iron including the sintering plant, although sinter plant is not incorporated in this project and despite its omission, a higher figure of Rs 10·50/tonne is taken for this project report.)			
3. Utility, services, shop requirements and common work expenses such as steam, water, etc.			
4. (i) Depreciation and Indirect costs			Rs 5·00
(ii) Wages, overheads etc.			Rs 25·00
Gross production cost of one tonne of-pig iron.			Rs 12·00
			Rs 163·50
5. *Credits*			
(i) Low-shaft furnace gas available to other shops having a calorific value of 1 350 kcal/nm³ @Rs 8·50 for 10^6 Kcal.			Rs 28·40
(ii) Slag and flue dust			Rs 1·50
Gross credit/tonne of pig iron			Rs 29·90
Net cost of production/tonne pig iron			Rs 133·60

TABLE XXII Burden calculation for the production of one tonne of pig iron with low temperature carbonized coke and medium size iron ore

No.	Raw materials	kg	Fe kg	Mn kg	P kg	S kg	CaO kg	MgO kg	SiO_2 kg	Al_2O_3 kg	F.C. kg
1.	Low temperature carbonized coke	3 308	39·41	—	7·60	11·25	48·66	16·10	460·94	239·89	2 034
2.	Punjab ore (Medium)	1 470	920·00	—	1·91	0·44	—	—	97·75	30·87	—
3.	Limestone (Madras)	882	—	—	—	—	479·01	8·82	7·76	10·58	—
4.	Limestone (Andhra)	441	2·03	—	—	—	142·00	110·25	1·32	2·47	—
5.	Manganese ore	36·8	2·06	18·66	—	—	—	—	4·12	3·79	—
	Total	6 137·8	963·50	18·66	9·51	11·69	669·67	135·17	571·89	287·60	2 034
	In the pig iron		920·40	4·50	9·50	0·60	—	—	64·0	—	35
	In the slag		43·10	14·16	—	11·09	669·67	135·17	507·89	287·60	—

Elements in pig iron kg		%	*Constituents of slag* kg		Corrected, kg		% Corrected
920·40	Fe	92·04	64·35	FeO	64·35	FeO	3·22
4·50	Mn	0·45	18·28	MnO	18·28	MnO	1·07
30·00	Si	3·00	669·67	CaO	650·28	CaO	38·80
9·50	P	0·95	135·17	MgO	135·17	MgO	8·00
0·60	S	0·06	507·89	SiO_2	507·89	SiO_2	30·12
35·00	C	3·50	287·60	Al_2O_3	287·60	Al_2O_3	17·00
			11·09	S	24·93	Cas	1·20
1 000·00		100·00			1 688·50		99·41

Fuel rate —2·03 tonnes F. C./tonne of pig iron.
Slag volume —1·68 tonnes/tonne pig iron.

$P_1\left(\frac{CaO}{SiO_2}\right)$ Corrected —1·22

$P_2\left(\frac{CaO+MgO}{SiO_2+Al_2O_3}\right)$ Corrected —1·08

slag can be suitably adjusted to have the most favourable slag/metal ratio and free flowing fluid slag consistent with adequate desulphurization and optimum silicon contents of the metal obtained.

The cost of iron ore used for direct charging in the low-shaft furnace industrial plant offers a price lower than that obtained with lumpy picked iron ore or screened after mechanised mining. The cost of the iron ore will again depend upon several regional considerations and is a factor which will be more favourable for a low-shaft plant than in the case of iron ore required in an integrated 1 million tonnes a year steel plant; the latter may be based on either sized iron ore or burdens or through the use of self-fluxing or non-fluxing sinter. These sinter plants need not be incorporated in a low-shaft furnace plant. It is with attendant lower capital costs thus deductable that the cost of iron production whilst being distinctly higher in a low-shaft furnace plant than in the case of big blast-furnace of an integrated 1 million tonnes a year steel plant, should still be quite favourable in relation to electric smelted pig iron. Of course, as in the case of electric smelted pig iron, the subsidizing of pig iron sale price (smelted in the low-shaft industrial unit) will need to be considered on a rational basis. It is re-emphasized that the economics of production will very largely depend on the plant's location vis-a-vis distribution of regional raw materials and their ready availability and the ultimate cost of the raw materials thus obtained at the plant site. It is, therefore, clearly stated that any fixed or unitary assessment of economic production for a plant to be located in any part of India would hardly be justified. The availability of regional raw materials and other ancillary facilities such as water, electric power, capacity to use the by-products obtained etc. will very largely determine the ultimate economics of the low-shaft iron smelting process. In any case, the economics of production will have to be determined in relation to actual cost criteria of raw materials prevailing in any one part of the country and interpolation of smelting costs in an industrial unit on the basis of investigation results actually obtained in the low-shaft furnace pilot plant of the National Metallurgical Laboratory. Depending on the different factors outlined above, such as availability of regional raw materials, ancillary facilities such as water, electric power and utilization of by-products, it is expected that the overall cost of production would be expected to be of the same order and in some cases, even lower than that in electric iron production smelting. In concluding, it is reemphasized that the actual cost of iron production in a low-shaft iron plant will vary from region to region in India and will depend in the ultimate analyses on the size and scope of the industrial low-shaft furnace plant.

The consumption of raw material and preliminary approximate production cost estimates for annual production of 100 000 tonnes of pig iron are given in Table XX.

Based on these data, the preliminary production cost estimate for annual output of 100 000 tonnes of pig iron by the industrial low-shaft furnace plant is given in Table XXI.

It is assumed that the capital investment for the entire iron production plant excluding low temperature carbonization plant for the non-coking coal may lie between Rs. 2–3 crores for 100 000 tonnes annual pig iron output, depending on the site location, cost and availability of services such as water, power etc. and related transport facilities and charges. The price of Kolsit required for iron smelting has been fixed on the basis of an independent low temperature carbonization plant where the requisite profit of the latter are effectively covered. It will also be observed that accordingly no credit has been allowed for carbonization plants' valuable by-products in the production cost estimates. It would also be quite possible to produce a special low sulphur, low phosphorus malleable grade of pig iron in this plant which can give a premium and can fetch a much higher price of about Rs. 300·00 per ton, yielding far increased trunover and profit.

B. Punjab

Due to non-availability of regional coal resources the smelting of iron ore from Mohindergarh district, Punjab was conducted with non-coking coal, low temperature carbonized coke (Kolsit and C.F.R.I.) and nut-coke with

TABLE XXIII Burden calculation for the production of one tonne of pig iron with low temperature carbonized coke and fine grained iron ore

No.	Raw materials	kg	Fe kg	Mn kg	P kg	S kg	CaO kg	MgO kg	SiO_2 kg	Al_2O_3 kg	F.C. kg
1.	Low temperature carbonized coke	2 940	35·16	—	6·76	9·99	43·41	14·37	411·25	214·03	1 808
2.	Punjab ore (Fines)	1 470	920·00	—	1·91	0·44	--	—	97·75	30·87	—
3.	Limestone (Madras)	882	—	—	—	—	479·01	8·82	7·76	10·58	—
4.	Limestone (Andhra)	368	1·69	—	—	—	118·49	92·00	1·10	2·05	—
5.	Manganese ore	36·8	2·06	18·66	—	—	—	—	4·12	3·79	—
	Total	5696·8	958·91	18·66	8·67	10·43	640·91	115·19	521·98	261·33	—
	In the pig iron		921·20	4·50	8·70	0·60	—	—	64·00	—	35
	In the slag		37·71	14·16	—	9·83	640·91	115·19	457·98	261·33	—

Elements in pig iron kg		%	*Constituents of slag* kg		Corrected, kg		% Corrected
921·2	Fe	92·12	48·48	FeO	48·48	FeO	3·13
4·5	Mn	0·45	18·28	MnO	18·28	MnO	1·11
30·00	Si	3·00	640·91	CaO	622·69	CaO	40·72
8·70	P	0·87	115·19	MgO	115·19	MgO	7·44
0·60	S	0·06	457·98	SiO_2	457·98	SiO_2	29·50
35·00	C	3·50	261·33	Al_2O_3	261·33	Al_2O_3	16·91
			9·83	S	22·14	CaS	1·18
1 000·00		100·00			1 546·09		99·99

Slag volume—1·54 tonnes F.C/tonne pig iron.
Fuel rate —1·80 tonnes F. C./tonne pig iron.

$P_1\left(\frac{CaO}{SiO_2}\right)$ Corrected—1·38

$P_2\left(\frac{CaO+MgO}{SiO_2+Al_2O_3}\right)$ Corrected—1·03

variations introduced in particle sizes of the iron ore. It was observed that smelting of this ore was fully feasible and also highly successful with either low temperature carbonized coke (Table XXIV) or nut-coke (Table XV). For smelting operations with nut-coke, the furnace stack height will have to be somewhat raised for ensuring effective heat exchange between the descending burden and ascending gases and promotion thereby of adequate metallurgical reaction between the two. As both these factors greatly affect the fuel rate and thereby reflect on the cost of iron production, stack height of the furnace for smelting operations with nut-coke will have to be somewhat suitably increased. In investigations conducted at the National Metallurgical Laboratory, hot blast at a temperature of 590° to 600°C was employed. In an industrial plant employing Cowper stoves, the blast can be preheated to the temperature of the order of 800° to 850°C and the higher input of sensible heat through the hot air blast would thereby effectively lower the fuel rate. It was observed that the fuel consumption dropped with continuous and sustained smelting operations under identical raw material conditions. It is, therefore, reasonable to extrapolate that with a higher air blast temperature of 850°C coupled with a continuity of smelting operations with identical raw materials, fuel consumption will come down to about 1·2 tonnes of nut-coke per tonne of pig iron. Further economy in the fuel rate would also be distinctly possible after proper matching of raw materials under commercial conditions.

Despite these factors, a somewhat higher amount of fuel will be required than in a conventional sized 1 000–1500 tonnes/day iron blast-furnace. The burden calculations with low temperature carbonized coke medium or fine sized iron ore are recorded in Tables XXII and XXIII respectively.

The cost of iron ore and flux employed for smelting in a low-shaft furnace or a small blast-furnace is expected to be considerably lower than for those employed in a conventional blast-furnace, as a large amount of ore fines can be tolerated in the burden of the former.

The availability of the essential ingredients and ancillary facilities, such as availability of water, electrical power, etc. will largely determine the exact geographical and physical site location of the industrial pig iron smelting plant.

Mohindergarh iron ore can be smelted with either nut-coke or low temperature carbonized coke for the production of foundry grades of pig iron and economics of the processes will obviously depend upon the cost of fuel inclusive of freight and availability of other ancillary facilities.

It would also obviously not be wise to wait for the installation of a soft coke carbonization plant. It would also be not considered premature if a specific recommendation is made that industrial scale smelting of Punjab iron ores should be done in a low-shaft or small blast-furnace utilising surplus nut-coke from Bhilai steel plant or from the Durgapur steel plant of Hindustan Steel Limited. It is known that several hundred thousand tonnes of the surplus nut-coke are today accumulated and are available both at Bhilai and Durgapur. It is also expected that this surplus by-product nut-coke would be readily available in years to come as well. The problem thus posed is whether one should transport foundry grades of pig iron from these integrated million tonnes steel plants from Bihar and Madhya Pradesh to the north or the surplus metallurgical nut-coke from these regions, considering that tonnages involved in either case would be more or less the same. However, the advantages of regional establishment of an industrial production iron plant in the Punjab is to be strongly favoured for more than one reason ; chief of which will be that by producing foundry grades of pig iron on a regional basis, the integrated million tonnes iron and steel complexes will be relieved of making an intermediate product, i.e. pig iron and would thereby be making basic iron to produce tonnage steel and its end products for which the integrated units have been primarily established. It is also to be emphasized that the establishment of regional iron production plant in the north should not be viewed basically from the somewhat narrow considerations of long transport haulage of the fuel. It is, therefore, to be assumed that pending the establishment of soft coke low temperature carbonization plant, one of which could also be based on Kalkote (Jammu) coal which is now being extensively mined, adequate quantities of surplus nut-coke should be made available by the Hindustan Steel and other private sector iron and steel plants to the Punjab for its projected iron smelting industrial unit.

It would thus be recommended that iron production plant in the Punjab should be based on the use of regional iron ores whilst utilizing surplus metallurgical nut-coke and effecting full recoveries of all the by-product values. Based on these considerations, it is reasonably expected that the cost of production in an industrial plant of about 100 000 tonnes of pig iron output per year will be of the same order as in an electric smelting iron production plant operating elsewhere or even somewhat lower. It will be fairly reasonable to arrive at a fuel rate of about 1·2 to 1·3 tonnes of nut-coke per tonne of pig iron, whilst the flux consumed would not be materially different from that encountered in an integrated iron and steel complex. With the limestone flux available in the Punjab, composition of the blast-furnace slag can be suitably adjusted to have a most favourable slag/metal ratio and to obtain a free flowing fluid slag consistent with adequate desulphurization and required silicon contents of the metal required for different foundry grades.

The cost of iron ore fines used for direct charging in the small blast-furnace should be lower than that of lumpy sized iron ores used in integrated iron and steel million tonnes a year plant. Whilst in the case of integrated million tonnes a year steel plant, incorporation of a sinter plant for utilization of iron ore fines would be a total necessity, in the case of low-shaft or small blast-furnace, iron ore fines can be charged directly into the furnace. It is with such attendant lower capital cost thus obtainable that the cost of iron production even while being somewhat distinctly higher in the small blast-furnace in relation to a giant blast-furnace, should still be quite favourable in comparison with electric smelted pig iron. It is also emphasized that the overall economics of production will largely depend on the plant's physical location vis-a-vis distribution of regional raw materials and their ready availability etc. It is therefore also felt that it will not be appropriate to apply any fixed or unitary yardstick for assessment of economics of production for a small scale iron production plant based on the use of regional raw materials. In the case of the Punjab, exact location will have to be determined in relation to the railway system which contains both the metre gauge and broad gauge. A site will have to be chosen wherein both the metre and broad gauge rail tracks are in close proximity to each other and will thus permit the haulage of the nut-coke from Bhilai or Durgapur by the broad gauge rail system whilst permitting the transport of iron ore and limestone by the metre gauge rail track. It has been ascertained that in order to accomplish this, the plant may have to be located near about Hissar which will be within a radius of 45–50 miles from the iron ore rich regions of the Punjab. It will also be fairly close to the Batala iron foundries, the number of which exceed over a hundred and which would provide the main consumption centres for the foundry grades pig iron to be produced in the pig iron making plant. It will also be up to the Punjab Government to rationally determine the actual cost criteria of the raw materials required and its ability to supply other requisite ancillary facilities, such as water, land, etc. A small quantum of electric power would also be needed to run the low-shaft or small blast-furnace plant. All these considerations will in the ultimate analyses determine the overall economics of iron production

TABLE XXIV Norms for the operation with nut coke per tonne of pig iron

Raw materials	Actual 'A' (Low Shaft Furnace Pilot Plant of National Metallurgical Laboratory) (in tonnes)	Estimated 'B' (for 100 000 tonnes a year production plant) (in tonnes)
Iron ore	1·5	1·5
Limestone	0·8–0·9	0·5–0·6
Nut-coke	1·54 (F.C.)	1·1

F.C.=Fixed carbon content in fuel

whilst in the following pages the cost of iron production has been calculated on the basis of results obtained in the National Metallurgical Laboratory's Low-Shaft Furnace Pilot Plant and due interpolation of the pilot plant scale results and cost of production on an industrial basis.

Capital cost estimates as given below have been as realistically determined as possible in relation to availability of capital equipment both of indigenous make and that imported from sterling areas.

PUNJAB PIG IRON PROJECT

(1) *Estimated Projected Cost*	
(2) *Land-Area in acres*	80–90 acres
(a) for the present project	30–35 acres
(b) for expansion	25–30 acres
(c) Housing Colony	30–40 acres
(3) *Buildings-Covered area*	
(a) for factory	6–8 acres
(b) for administrative and other buildings	3–4 acres
(4) *Plant Machinery*	
(a) Pig Iron Plant	*100 000 tonnes pig iron output per year
(i) Imported	35–40%
(ii) Indigenous	60–65%
(b) Workshop and maintenance	Rs 3·5 lakhs excluding workshop building
(c) Auxiliary equipment for internal transport etc.	Rs 1·5 lakhs
(5) *Raw materials (annual requirements)*	
(a) Iron ore 50–60% Fe	150 000 tonnes
(b) Limestone 36–40% CaO	55 000 tonnes
(c) Nut-coke	150 000 tonnes
(6) *Services*	
(a) Quantity of power required in terms of actual load and kWh per day per tonne of pig iron	300 kWh per tonne of pig iron (electrically driven blowers)
(b) Quantity of water required per day	The water will have to be recirculated through a recirculation system and make up water 5-6 lakhs gallons per day excluding requirements of township, will be needed
(7) *Staff and Labour*	
(a) Managerial	6 posts
(b) *Supervisory*	
(i) Technical	12 ,,
(ii) Non-technical	5 ,,
(c) Clerical	15 ,,
(d) Labour	
(i) Skilled	200 posts—3 shifts.
(ii) Semi-skilled	
(iii) Unskilled	
(iv) Other categories	

(*If a 14 ft diameter small blast-furnace with 250–300 tonnes daily capacity is established, it will produce about 100 000 tonnes of pig iron per year. The capital cost for the furnace and its auxiliaries will be of the order of 1·30 crores of rupees. In relation to this, if 3 small blast-furnaces of 100 tons daily capacity each are installed yielding 35 000×3=100 000 tonnes of iron per year, total capital cost of the small furnaces and their auxiliaries will be of the order of rupees 2·50 crores. It will thus be seen that it would be desirable to have a small low-shaft blast-furnace of about 300 tonnes daily capacity with a 13–14 ft hearth diameter. These estimates are based on enquiries made from a British group of iron blast-furnace suppliers who have been closely connected with the establishment of the Durgapur Iron and Steel Plant of the Hindustan Steel Limited).

TABLE XXV Burden calculation for the production of one tonne of pig iron in an industrial furnace

No.	Raw materials	kg	Fe kg	Mn kg	P kg	S kg	CaO kg	MgO kg	SiO_2 kg	Al_2O_3 kg	F.C. kg
1.	Nut coke	1 100	13·26	—	1·52	5·50	8·39	4·68	114·92	72·93	825
2.	Punjab iron ore	1 470	920·00	—	1·91	0·44	—	—	97·75	30·87	—
3.	BISRA lime stone	390	—	—	—	—	174·72	12·75	27·14	6·24	—
4.	BISRA dolomite	150	—	—	—	—	48·90	30·60	5·85	2·40	—
5.	Manganese ore	36·8	2·06	18·66	—	—	—	—	4·12	3·79	—
	Total	3 146·8	933·32	18·66	3·43	5·94	232·01	48·03	249·78	116·23	825
	In the pig iron		924·47	6·50	3·43	0·60	—	—	64·00	—	—
	In the slag		8·85	12·16		5·54	232·01	48·03	185·78	116·23	

Elements in pig iron kg		%	*Constituents of slag* kg		Corrected, kg		% Corrected
924·47	Fe	92·447	11·34	FeO	11·34	FeO	1·80
6·50	Mn	0·65	15·50	MnO	15·50	MnO	2·50
30·00	Si	3·00	232·01	CaO	222·52	CaO	36·40
3·43	P	0·343	48·03	MgO	48·03	MgO	7·80
0·60	S	0·06	185·78	SiO_2	185·78	SiO_2	30·30
35·60	C	3·50	5·54	S	12·36	CaS	2·00
			116·23	Al_2O_3	116·23	Al_2O_3	19·00
1 000·00		100·00			611·76		99·80

Fuel rate—0·83 tonnes F.C./tonne of pig iron.
Slag volume—0·61 tonnes/tonne of pig iron.

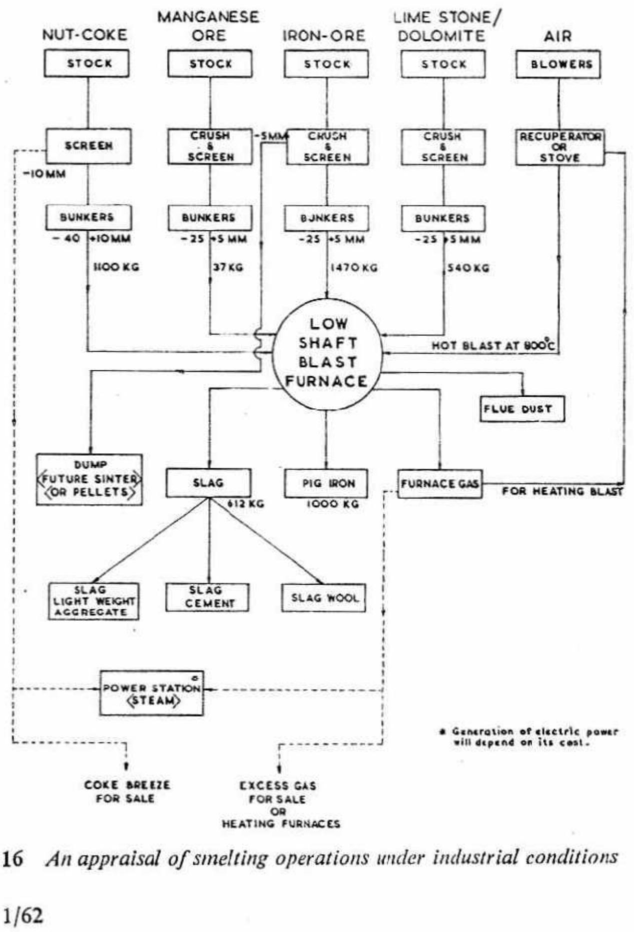
$P_1\left(\frac{CaO}{SiO_2}\right)$ Corrected—1·20

$P_2\left(\frac{CaO+MgO}{SiO_2+Al_2O_3}\right)$ Corrected—0·89

Operational economics

The consumption of raw materials and approximate production cost for an annual output of 100 000 tonnes of pig iron are given in Table XXIV.

As outlined in the preceding pages, the fuel consumption per tonne of pig iron is directly related to several factors, such as size of the furnace, nature of the fuel, particle sizes of the raw materials charged and constancy of smelting operations over long periods. These factors have a direct influence on the fuel rate whilst high hot



16 *An appraisal of smelting operations under industrial conditions*

TABLE XXVI Initial production cost estimates per tonne of pig iron based on an annual output of 100 000 tonnes of pig iron

Description	Required per tonne of pig iron (in tonnes)	Cost per tonne of pig iron inclusive of freight (in Rs.)	Total cost/ tonne of pig iron (in Rs.)
1. *Materials* (Suitably screened and sized)			
(i) Iron ore	1·5	16·00	24·00
(ii) Limestone	0·6	12·00	7·00
(iii) Nut coke	1·1	97·00 (Rs. 47 per tonne controlled price of nut coke plus cost of rail transport).	106·00
			137·00
2. *Power requirements* (It will be necessary to employ steam blowers instead of electrically driven air blast blowers in order to utilise the low shaft furnace gas for steam raising purposes. However, in a million tonnes a year steel plant, the figure of electric power requirement is of the order of Rs. 8·60 per tonne of pig iron including the sintering plant etc. In this project, the sinter plant has not been included since iron ore and other materials fines will be charged to the furnace direct).			8·00
3. *Utility, services shop requirements and common work expenses such as steam, water, etc.*			4·00
4. (i) Depreciation and indirect costs (@ 12% per annum).			20·00
(ii) Wages, overheads etc.			10·00
			30·00
Gross production cost of one tonne of pig iron			179·00
5. *Credits*			
(i) Low shaft furnace gas available to other shops 2 400 nm³/h having a calorific value of 1 350 Kcal/nm³ @ 8·50 for 10^6 kcal			28·40
(ii) Slag and flue dust			1·60
Gross credit/tonne of pig iron			30·00
Net cost of production/tonne of pig iron			149·00

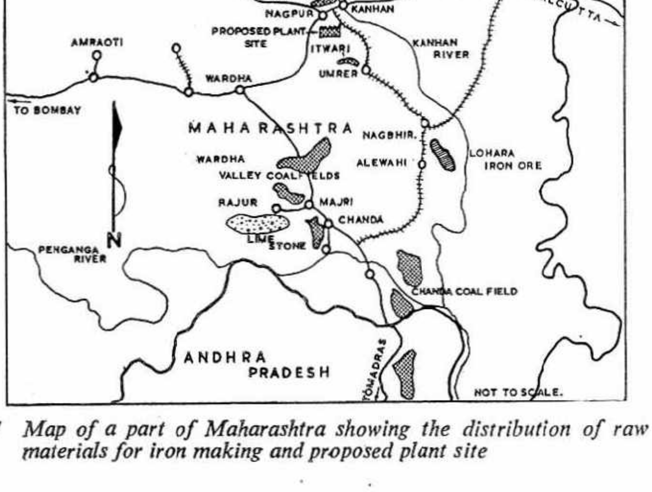
TABLE XXVII Computation of annual profit and loss statements for total capital investment of Rs 3 crores

Product	Quantity/ year (in tonnes)	Production cost per tonne Rs	Production cost per year Rs	Net profit per tonne Rs	Net profit per year Rs	Gross return as % of capital
Foundry pig iron	100 000	149	14 900 000	100*	10 000 000	30–33%

air blast temperature, uniformity of smelting operations and overall operational improvements will indirectly lower the fuel rate. Considering that in the Low-Shaft Furnace Pilot Plant, it was possible to attain a fixed carbon rate of 1·54 tonnes per tonne of pig iron, in an industrial unit of 250–300 tonnes per day, a fuel rate of 1·1–1·2 tonnes per tonne of pig iron could be most reasonably expected. If, however, a smaller low-shaft blast furnace of 100 tonnes daily output is used, the fuel rate could be of the order of 1·2 to 1·3 tonnes of nut coke per tonne of pig iron. A burden calculation based on a fuel rate of 1·1 tonnes of nut coke/tonne of pig iron is given in Table XXV. An appraisal of the smelting process under industrial plant conditions is given in the flow diagram in Fig. 16.

The use of low temperature soft coke for iron production is not being taken into account in these cost estimates in view of the non-existence of industrial scale units for the production of low temperature carbonized soft coke. As such, the production costs are based on the use of the raw materials as given below. Based on the above norms, the iron production cost for an annual output of 100 000 tonnes of pig iron in industrial low-shaft or small blast-furnaces is given in Table XXVI.

It may be stated that in these capital cost estimates, the cost of township and the land to be acquired by the Government have not been taken into account whilst availability of water and electric power at the plant site has been presumed. If depreciation of the land and buildings capital costs is also reckoned, production cost may go up by a couple of rupees per tonne of iron. At the



17 *Map of a part of Maharashtra showing the distribution of raw materials for iron making and proposed plant site*

TABLE XXVIII Computation of annual profit and loss statements for total capital investment of Rs 1·5 crores

Product	Quantity/ year (in tonnes	Production cost per tonne Rs	Production cost per year Rs	Net profit per tonne Rs	Net profit per year Rs	Gross return as % of capital
Foundry pig iron	100 000	149	14 900 000	100*	10 000 000	65%

* Depending upon the retention price negotiated with the Iron & Steel Control as has been done for other Indian Iron & Steel Plants including Mysore Iron & Steel Works.

same time having in view the present market prices imposed by the Government, there would not be any retention price or price control over the sale of pig iron for small scale iron melting plants. On that basis, it would be possible to obtain a selling price of about Rs. 250/- to 300/- per ton F.O.R. depending on the grade and quality of the foundry iron produced. Even on a pessimistic estimate of the selling price of iron and applicability of the retention price, a profit of about Rs. 100/- per tonne of iron would be possible. In terms of the capital investment of the order indicated earlier, the gross return of 30–33% will not be too high an estimate to be expected, if a total capital investment of Rs. 3 crores is made (Table XXVII) if only one furnace of 300 tons daily output is installed, capital cost will be of the order of Rs. 1·5 crores and return on the capital would be 65% (Table XXVIII).

C. Maharastra

For a projected iron smelting unit in Maharastra, investigations were conducted with their regional raw materials. While the quality of iron ore (Table I No. 6) and lime stone (Table II No. 4) were admirably suitable for smelting iron, non-coking coals from Wardha and Kanhan Valleys were extremely friable, readily broke up even under hand pressure, and besides these were crumbled to pieces on weathering. Although low-shaft furnace smelting permits utilization of raw materials of substandard crushing strength, the extreme friability of Maharashtra coals will not enable them to withstand the burden load even in a low-shaft furnace or a small blast furnace. Based on pilot plant trials in the low-shaft furnace of the National Metallurgical Laboratory, it was concluded that direct utilisation of non-coking coals from Kanhan-Kamptee, Hindustan Lalpeth, Ghughus collieries of Maharastra will not be possible for iron making in a low-shaft furnace charged either directly in lumpy bedded form or through one component burden as self-fluxing briquettes.

The distribution of raw materials and proposed location of the site are shown in Fig. 17. It is understood that non-coking coal from the Umrer Colliery is better than the coals of Wardha and Kanhan. The carbonization characteristics of non-coking coals from the Kanhan and Pench Valley coal fields in Madhya Pradesh and Umrer coal can be evaluated in due course, but pending the installation of low temperature carbonization plant, a low-shaft or small blast-furnace based on the utilization of nut coke should be favourably considered in the initial stages. The furnace can be suitably designed to operate on either of these two fuels. The spare nut coke could be obtained from the existing integrated heavy iron and steel plants in India.

Such an industrial unit will meet the regional requirements of the foundry pig iron in Maharastra, Andhra and Punjab the demand for which will increase with successive Five Year Plans.

It is hoped that based on these comprehensive investigation trials undertaken by the National Metallurgical Laboratory, further action will be taken by both private and public sectors and particularly by the States of Maharashtra, Punjab and Andhra for taking urgent and necessary steps for the establishment of iron smelting plants to meet the regional requirements of foundry grades of pig iron.

CONCLUSIONS

Based on three years of extensive pilot plant trials with raw materials of widely different physical and chemical characteristics, it was concluded that :

(i) The use of nut-coke caused minor irregular descent of burden associated with high top gas temperature and high CO/CO_2 ratio chiefly due to short stack height leading to poor utilization of sensible and chemical heat.

(ii) The furnace top gas temperature depended on the nature of the fuel and particle size of raw materials.

(iii) The CO/CO_2 ratio improved with decrease in the particle sizes of raw materials particularly iron ore and limestone with consequent improvement in fuel rate.

(iv) The D. H. N. process of iron smelting of one component burden i.e. self-fluxing briquettes was associated with serious operational difficulties rendering the process altogether impractical. Furthermore unfavourable economics due to heavy cost of binders makes the process totally uneconomical and thus unacceptable under Indian conditions.

(v) Employment of non-coking coal in bedded form of burden generally led to serious operational difficulties and cannot be adopted or recommended for low-shaft iron smelting.

(vi) The use of low temperature carbonized coke made out of wholly non-coking coals furnished exceedingly smooth and successful furnace smelting operations associated with minimum fuel and flux rates and desired foundry grades of pig iron.

(vii) Smelting conditions in the low-shaft furnace facilitate production of high silicon pig iron such as of foundry grade I.

(viii) By suitable adjustment of slag basicity and optimum additions of MgO through dolomite in the flux, adequate slag fluidity and production of uniform and acceptable grades of foundry pig iron was ensured.

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